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NATIONAL GUIDELINES ON PHYSICAL-CHEMICAL-BIOLOGICAL TREATMENT OF HAZARDOUS WASTE

Environment Canada Environnement

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National Guidelines on Physical-Chemical-Biological Treatment of Hazardous Waste

Canadian Council of the Ministers of the Environment

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PREFACE

This guideline document has been commissioned as part of the Canadian Council of Resource and Environment Minister's Hazardous Waste Action Plan announced in March 1987. The Action Plan calls for the drafting of national guidelines for Hazardous Waste Incineration, Physical-Chemical-Biological Treatment, and Landfilling to ensure the protection of the natural environment and public health. This document sets forth the guidelines for Physical-Chemical-Biological Treatment of hazardous wastes.

The guideline document is intended for use by provincial and federal authorities and provides reference on basic design, operating and performance standards for the physical-chemical-biological treatment of hazardous wastes. It also provides a framework of principles, methodologies and minimum standards which if adhered to should minimize the risks to human health and the environment from physical-chemical-biological facilities for the treatment of hazardous wastes.

Sections 1.0 and 2.0 of this report provide an overview of the typical processes that are used in Physical-Chemical-Biological treatment of hazardous wastes and the various approaches that can be used to develop guidelines for these types of facilities in Canada. Sections of the report review the effectiveness of treatment processes and levels of attainability for effluent discharges.

Succeeding sections of the report review and recommend guidelines dealing with operational risk, site selection, monitoring contingency planning and decommissioning. A compilation of all guidelines is presented in pages vi through xii immediately following. A bibliography of references is presented in Appendix C.

SUMMARY OF RECOMMENDED GUIDELINES

Presented below is a compilation of all guidelines presented in this document. The reader is urged to refer to the section pertaining to a particular guideline.

SECTION 1.0 INTRODUCTION

1-1 **Wastes treated in the physical-chemical-biological facilities must undergo treatment to the fullest extent possible, using best available technology that will minimize the risk to human health and to the environment.**

SECTION 2.0 REVIEW OF PHYSICAL-CHEMICAL-BIOLOGICAL TREATMENT PROCESSES

2-1 **One of the key philosophies which should be adopted for the design of the physical-chemical-biological treatment system is, that batch methods be used to the extent possible to maximize control and effectiveness of each stage of the treatment process.**

2-2 **Preference should be given to technologies and process systems that produce the lowest quantity of residues and that can detoxify and concentrate residual contaminants removed from the waste to the greatest extent. Preference should also be given to technologies which produce residues:**

- **requiring minimum further treatment prior to disposal,**
- **which are most amiable to subsequent treatment,**
- **which can be readily rendered both physically and chemically stable by the solidification process prior to landfilling.**

SECTION 3.0 EFFECTIVENESS OF THE TREATMENT PROCESS

3-1 **Careful matching of waste type and treatment technology, coupled with pilot scale tests to ascertain optimal operating conditions, is required to achieve high levels of treatment efficiency through the physical- chemical-biological treatment process.**

3-2 **Batches of waste destined for physical-chemical-biological treatment should have a treatment recipe assigned to it in advance of arrival at the facility. Once an optimum treatment recipe has been developed for a generator's waste, the same recipe can be applied to successive batches of waste from the same generator. Additional treatability testing should only be required if the fingerprint analysis indicates a change in waste characteristics.**

SECTION 4.0 OPERATIONAL RISKS

4-1 **All waste storage, process reagent storage and treatment processes within the physical-chemical-biological facility should be carried out in vessels which are totally enclosed and vented. Any vented gaseous emissions should be treated before they are discharged into the atmosphere.**

4-2 Storage tanks and reaction vessels should be under slight negative pressure. This should prevent fugitive gaseous emissions from escaping into the process buildings.

4-3 Curbs around the base of each storage tank and reaction vessel should be provided to prevent migration of accidental spills or overflows. The curbs should be capable of containing the entire contents of the vessel.

4-4 Emergency eye wash shower stations and respiratory equipment should be provided at strategic locations within the treatment facility.

4-5 Care should be taken to ensure that contaminated materials are not inadvertently tracked from the active areas of the physical-chemical-biological facility. Mandatory daily changes into clean work clothes is required.

SECTION 5.0 SITE SELECTION

5-1 Site selection must address geotechnical, land use, biological socio-economic impact, human and environmental factors, past, present and potential future uses of the site.

5-2 In the early stages of site selection, a mechanism such as constraint criteria mapping should be used as a screening process to warrant either exclusion or inclusion of a site. This process should be employed for detailed comparative evaluation amongst alternate sites.

5-3 A staged approach for public participation should be carried out based on public awareness of why the facility is needed and recognition that public values and environmental quality will not be depreciated.

SECTION 6.0 MONITORING

6-1 Sample analysis and treatability test information should be used to establish treatment recipes for wastes prior to physical-chemical-biological treatment.

6-2 Quality control checks should be carried out during the treatment sequence to ensure that treatment is proceeding as planned.

6-3 Quality control checks should be carried out after treatment to confirm that the treated effluent meets the required standard.

6-4 All personnel at the physical-chemical-biological facility should be subjected to both pre-employment and regular medical examinations.

6-5 In addition to the regular source monitoring program, a quality assurance program should be initiated, preferably by an outside laboratory.

SECTION 7.0 EFFLUENT CRITERIA

7-1 Dilution or blending of hazardous waste residues or effluents should not be allowed for the sole purpose of achieving permitted concentration limits.

7-2 Effluent attainability criteria is available for a number of inorganic and organic parameters of concern. It is important to emphasize that there is considerable variability in these data depending upon the treatment application, waste types and influent contaminant concentrations. The recommended effluent parameters in Tables 7-6 and 7-7 should provide sufficient environmental protection. Due to the vast number of *organic* compounds, it is difficult to establish effluent criteria for all wastes and all compounds. Appendix D summarizes levels of attainability for many organics and may be used along with Tables 7-3 and 7-5 as a rough guideline for specific organics once the individual characteristics of the waste stream are known.

7-3 The following measures should be incorporated into the design of treatment facilities wherever possible.

- Direct unloading of waste from tanker trucks to storage tanks by way of sealed interconnected piping to avoid any emission of vapours.
- Vent systems installed on all receiving tanks, storage tanks and blending or mixing vessels, to capture any vapours that may be generated. Contaminant removal systems such as activated carbon units or scrubbers should be installed to clean the vent air prior to release. Alternatively, the vent air could be discharged to an incinerator, if available.
- Treatment of wastes should be carried out in enclosed vessels with vent systems or contaminant removal systems.
- Minimization of waste and reagent transfers, with treatment, performed as close to reagents and to ultimate disposal.
- Containment or minimization of particulate emissions arising from the solidification/stabilization process and landfill disposal. Solids should be transferred in slurries where possible to eliminate dust emissions.
- Particular attention should be exercised in areas where operator error could result in conditions that cause the production of toxic emissions. These areas should be enclosed and equipped with vent gas treatment equipment.
- Good housekeeping and maintenance should be practiced to avoid leaks, spillage and to ensure proper operation of vent systems.

TABLE 7-6

RECOMMENDED EFFLUENT CRITERIA FOR PHYSICAL-CHEMICAL-BIOLOGICAL PLANT

(Inorganics and Physical Parameters)

Parameter	Maximum Concentration or Range in (mg/l) unless otherwise specified
Physical	
pH	6.5 to 8.5
Temperature	32°C
Suspended Solids	15
Toxicity Limit (bioassay)	100% effluent
Inorganics	
Aluminum, dissolved	0.1
Ammonia, dissolved (as N)	1.0
Antimony, dissolved	0.25
Arsenic, dissolved	0.1
Barium, dissolved	1.0
Boron, dissolved	10.0
Cadmium, dissolved	0.1
Chromium, dissolved (hexavalent)	0.1
Chromium, total	0.5
Cobalt, dissolved	0.1
Copper, dissolved	0.1
Cyanide (as HCN)	0.1
Fluoride, dissolved	15.0
Lead, dissolved	0.1
Manganese, dissolved	0.5
Mercury, total	0.001
Molybdenum, dissolved	0.5
Nickel, dissolved	0.5
Selenium, dissolved	0.05
Tin, dissolved	0.5
Zinc, dissolved	0.2

Source: B.C. Ministry of Environment and Parks, "Special Waste Regulation," March 1988

TABLE 7-7

RECOMMENDED EFFLUENT CRITERIA FOR PHYSICAL-CHEMICAL-BIOLOGICAL PLANT

(Selected Organics)

Parameter	Maximum Concentration or Range in (mg/l) unless otherwise specified
Organics	
5 day Biochemical Oxygen Demand	20
Oil	10
Phenol	0.02
Polychlorinated biphenyls, total	0.005
Polychlorinated dibenzo furans, total	30 ng/l
Polychlorinated dibenzo-p-dioxins, total	30 ng/l
Total organic halogens	0.5
Aldrin	6×10^{-5}
Lindane	6×10^{-6}
Methylene Chloride	0.5
Carbon Tetra Chloride	0.013
Trichloroethyene	0.025
Chloroform	0.006
Bis (2-Chloroethyl) ether	0.1
Benzene	0.015
Hexachlorobenzene	5×10^{-4}
Acenaphthene	0.012
Benzo (k) Fluroanthene	0.001
Butyl-Benzyl-Phthalate	6×10^{-4}
Acrylonitrite	0.20
2, 4, 6-Trichlorophenol	0.002
2-Chlorophenol	0.002

Source: Shuckrow et al, 1981
U.S. EPA, "Hazardous Waste Treatment Technology," EPA/600/D-86/006, 1986

7-3 **The following measures should be incorporated into the design of treatment facilities wherever possible.**

- **Direct unloading of waste from tanker trucks to storage tanks by way of sealed interconnected piping to avoid any emission of vapours.**
- **Vent systems installed on all receiving tanks, storage tanks and blending or mixing vessels, to capture any vapours that may be generated. Contaminant removal systems such as activated carbon units or scrubbers should be installed to clean the vent air prior to release. Alternatively, the vent air could be discharged to an incinerator, if available.**

- Treatment of wastes should be carried out in enclosed vessels with vent systems or contaminant removal systems.
- Minimization of waste and reagent transfers, with treatment, performed as close to reagents and to ultimate disposal.
- Containment or minimization of particulate emissions arising from the solidification/stabilization process and landfill disposal. Solids should be transferred in slurries where possible to eliminate dust emissions.
- Particular attention should be exercised in areas where operator error could result in conditions that cause the production of toxic emissions. These areas should be enclosed and equipped with vent gas treatment equipment.
- Good housekeeping and maintenance should be practiced to avoid leaks, spillage and to ensure proper operation of vent systems.

SECTION 8.0 CONTINGENCY PLANNING

8-1 A comprehensive contingency plan should be prepared for the physical-chemical-biological facility. It should be distributed and reviewed by all staff, and should include any realistically foreseeable mishaps which may occur at the physical-chemical-biological facility. The plan should be prepared in consultation with provincial and local emergency response authorities.

8-2 The contingency plan for the facility should be reviewed and amended on a regular basis to reflect changes in personnel, response procedures, technology or response equipment.

8-3 All physical-chemical-biological plant personnel should be given regular comprehensive training programs. These training programs should include local community emergency response personnel.

SECTION 9.0 DECOMMISSIONING

9-1 Plans for the decommissioning of the physical-chemical-biological facility should be prepared as a part of the initial planning and design phase. The decommissioning plan should be updated if it is any way affected by changes in facility design or its operating procedures.

9-2 The owner or operator of the physical-chemical-biological facility should be required to close the facility in a manner that:
- minimizes the further need for maintenance,
- prevents the escape of any hazardous contaminants to the environment.

9-3 When the plant is decommissioned, all equipment and structures used at the site should be decontaminated or dismantled and disposed of in a safe manner.

9-4 **The decommissioning plan should provide a description of the activities which should be conducted after final closure of the site. These should include the following:**

- **maintaining the functional integrity of the area,**
- **maintaining the monitoring systems,**
- **protection and maintenance of survey or environmental benchmarks,**
- **control of access to the site in accordance with its approved decommissioned use.**

1.0 INTRODUCTION

Alberta Environment, Industrial Waste Branch, is coordinating the development of national guidelines on the physical-chemical-biological treatment of hazardous wastes, under the Canadian Council of Resource and Environment Minister's Hazardous Waste Action Plan: 2.1(b).

1.1 Scope of Document:

The topics covered in this document include the following:

- review of regulatory requirements and effluent criteria for physical-chemical-biological treatment in various jurisdictions
- review of physical-chemical-biological treatment processes
- site selection
- recommended criteria pertaining to the design and operation of hazardous waste physical-chemical-biological treatment facilities
- requirements for process, environmental and source monitoring
- recommended approach to regulation of liquid, solid and air emissions
- contingency planning
- recommended decommissioning procedures

1.2 Purpose of Document:

This guideline document is intended for use by provincial and federal authorities and provides reference on basic design, operating and performance standards for the physical-chemical-biological treatment of hazardous waste.

The report provides an overview of various processes used in physical- chemical-biological treatment. More detailed descriptions of typical facilities are included in the Appendices. This report is not intended to be a complete state-of-the-art technology review as this information can be obtained by referring to the numerous publications provided in the bibliography.

1.3 Approach to Developing the Document:

1.3.1 Types of Guidelines

In developing national guidelines for a physical-chemical-biological treatment facility, it is necessary to review the types of guidelines that may apply to the effluents. These guidelines are generally divided into three categories.

Facility design and operating guidelines

- require that specific equipment features, practices, procedures, etc. be incorporated into the design and operation of the facility.

Performance guidelines

- require a certain level of performance (usually treatment).

Risk assessment guidelines

- require the facility to meet a certain level of risk to human health and the environment.

An example of the physical-chemical-biological **facility design and operating guidelines** would be a requirement to "separately dyke all process vessels including those contained within buildings."

These types of guidelines are relatively straightforward and easily understood. They can be used by the plant owners, designers and regulators, each for their own purpose, and they are relatively easy to interpret and enforce.

On the other hand, design and operating **standards** discourage technical innovation and the development of new technology. They are inflexible and when applied to satisfactorily operating systems, they may result in situations inappropriate or uneconomic.

Performance guidelines are categorized as follows:

Technical Performance

- guidelines which specify that the physical-chemical-biological facility must meet certain requirements. An example would be that the facility should remove 90% of the Biochemical Oxygen Demand.

Effluent Performance

- guidelines which specify that a certain level of effluent must be achieved by the facility. An example would be specifying that the concentration of any contaminant should not exceed a certain level in the effluent.

Environmental Performance

- guidelines which specify a maximum allowable contaminant level in the ambient environment.

In the **risk assessment** approach guidelines are developed on the basis of the degree of hazard of a facility and the corresponding risk to human health and to the environment.

1.3.2 Level of Technology Based Limitations and Standards

The effluent limitations and standards contain limits on substances that can be discharged directly into public waterways (direct discharges) or indirectly into public sewer systems (indirect discharges). The limits are based on the treating or removing of the substances and are determined from the performance of technologies available and in some cases from process modifications. More stringent, site specific, limits can be applied to facilities based upon receiving water quality considerations.

Development of the specific effluent limits requires detailed evaluations of wastewater discharges and treated effluents; e.g. the sources and volumes of wastewater, the processes and sources and types of pollutants in the plant.

The evaluations enable the characterization of various controls and treatment options, determine their costs, both capital and annualized, and identify pollutant removals. Although the limits may not require any particular technology, they do require plants to achieve the effluent discharge which reflect the proper operation of technologies from which the performance data was used to generate the limits.

1.3.3 U.S. EPA Levels of Technology

By far the most comprehensive levels of technology studies on performance guidelines, and standards has been undertaken by the U.S. EPA. Once the collected data and information about an industry have been evaluated, a determination of which level of technology can be used as a basis for establishing the effluent limits. The major levels of technology are described below:

BPT: *Best Practicable Technology Currently Available*

The BPT level represents the average of the best existing performances of plants of various ages, sizes, processes, or other common characteristics for control of similar pollutants. A balance between the total cost of applying the technology against the effluent reduction benefits including: age of equipment and facilities, process changes required, engineering aspects of the control technologies, and non-water quality environmental impacts (including energy requirements) is made. BPT also focuses on end-of-pipe treatment rather than process changes or internal controls, except when these technologies are common industry practice.

BAT: *Best Available Technology*

This level represents the best economically achievable performance of plants varying in age, size processes, or other shared characteristics. BAT is the major method of controlling the direct discharge of toxic and non-conventional pollutants to navigable waters. Factors considered in defining BAT include the age of the equipment and facilities involved, the processes used, engineering aspects of the control technology, process changes, non-water quality environmental impacts including energy, and the costs of applying such technology.

Uniformly inadequate performance within a category or subcategory may require transfer of BAT from a different subcategory, and may include process changes or internal controls, even when these technologies are not common industry practice.

BAT limitations, in general, represent the best economically achievable performance of direct dischargers included in an industrial category or subcategory. BAT limitations control the discharge of toxics (priority pollutants) and non-conventional pollutants (COD, pheonolic compounds, ammonia and sulfides) in the effluent of existing direct dischargers. BAT does not regulate conventional pollutants (TSS, oil and grease, BOD5 and pH) which are considered under Best Conventional Treatment Economically Available (BCT).

BCT: *Best Conventional Pollutant Control Technology*

This level of technology control is not an additional limitation but replaces BAT for the control of conventional pollutants. The Best Conventional Pollutant Control Technology (BCT) limitations are assessed according to a two part "cost reasonableness" test. EPA must find that limitations are "reasonable" under both tests before establishing them as BCT. In no case can BCT be less stringent than BAT. The factors considered in assessing BCT for an industry are the relationships between the cost of attaining a reduction in effluents and the effluent reduction benefits attained at different levels of control within the industry, and a comparison of the cost and level of reduction of such pollutants by treatment works and industrial sources.

NSPS: *New Source Performance Standards*

New Source Performance Standards are applicable to new industrial direct dischargers. The basis for this level of control technology is the best available demonstrated technology aimed to reduce pollution to the maximum extent feasible. Factors considered are the best demonstrated process changes, in-plant control, and end- of-pipe treatment technologies. This level of control strongly emphasizes the fact that new plants have the opportunity to install the best and most efficient production processes and wastewater treatment technologies.

To further strengthen the toxic control program the EPA may prescribe "best management practices" (BMP) to prevent the release of toxic and hazardous pollutants from plant site runoff, spillage or leaks, sludge or waste disposal, and drainage from raw material storage associated with or ancillary to, the manufacturing or treatment process.

1.3.4 U.S. EPA Pollutants Regulated

Another major component of developing technology based regulations is the selection of individual pollutant parameters for regulations. The selection process by the U.S. EPA involves thorough analysis of literature and collected industry data, and conducting detailed sampling, screening and verification programs, e.g. analyzing raw and treated wastewater streams from several discrete operations generating wastewater. These analyses determine which pollutant is present, the performance of control technologies available that will remove the pollutant, and where the most effective removal can take place (either in-plant or at the end-of-pipe). Additionally, different pollution control systems are used for the removal of different classes of pollutants; e.g. metals vs. organics.

Moreover, depending upon the different matrices of wastewater conditions, limitations established for a particular pollutant may vary among the industrial categories and subcategories.

There are three groups of industrial pollutants for which effluent limitations, standards, and guidelines are established: "conventional," "toxic," and "non-conventional." A description for each group is provided below:

Group 1: *Conventional Pollutants*

"Conventional" pollutants represent the most familiar group of the pollutants generally accepted by professionals in the field of wastewater treatment. This group consists of the following

five parameters which are generic in character in that they are not specific compounds but measure classes of substances which have similar physical, chemical, or biological responses to empirical laboratory tests.

- biochemical oxygen demand (BOD)
- suspended solids (TSS)
- fecal coliforms
- pH
- oil and grease

Group 2: Toxic (Priority) Pollutants

As part of the amendments to the Clean Water Act in 1977, the United States Congress issued a list of 65 priority pollutants and classes of pollutants considered to be "toxic." This list was later expanded by the Agency into 129 specific toxic-priority pollutants, three of which have since been deleted. This list is included in Appendix "C." During the development of the categorical effluent regulations, the wastewater must be analyzed to determine whether any of the priority pollutants are present.

Regulations and standards must be developed and issued for toxic pollutants which:

- are present in greater than trace concentrations;
- represent significant hazards to water quality or human health;
- are above treatability levels in raw waste streams; or
- pass through or interfere with the operation of a public-owned treatment works.

In addition, EPA is required to identify and regulate pollutants, other than the priority pollutants.

Group 3: Non-Conventional Pollutants

Generically, the non-conventional group of parameters represents any pollutant or pollutant parameter that is not identified as either conventional or toxic. Non-conventional parameters which are commonly found in categorical guidelines and standards are included in Appendix C.

Guideline 1-1: Wastes treated in the physical-chemical-biological facilities must undergo treatment to the fullest extent possible using best available technology that will minimize risk to human health and the environment.

2.0 REVIEW OF PHYSICAL-CHEMICAL-BIOLOGICAL TREATMENT PROCESSES

The physical-chemical-biological treatment facility should be required to treat basically two categories of wastes:

- Inorganic waste (physical-chemical treatment)
- Aqueous/organic waste (biological treatment)

A description of the specific types of treatment processes is presented below. The majority of the wastes that require treatment in the physical-chemical-biological plant should be predominantly inorganic in nature. Therefore the physical-chemical-biological process system should be the predominant treatment system.

Guideline 2-1: One of the key philosophies which should be adopted for the design of the physical-chemical-biological treatment system is that batch methods be used to the extent possible to maximize control and effectiveness of each stage of the treatment process.

Earlier published reports such as Arthur D. Little Vols. I & II (1977), USEPA (1980) revised 1981, 1982 and 1983 have summarized the results of extensive literature reviews and evaluations on alternative technologies which can be used for the treatment of special wastes in physical- chemical-biological facilities.

2.1 Physical-Chemical Treatment:

2.1.1 General

Physical treatment processes generally refer to processes which are designed to separate and concentrate various components of a waste stream without chemically altering the form of these components. Filtration and sedimentation are two examples of physical treatment processes.

Chemical treatment generally refers to processes which bring about a chemical transformation of one or more components of a waste stream as the primary means of either removing a particular component or reducing its toxicity. Oxidation and precipitation are two examples of chemical treatment processes.

Limited aqueous organic wastes may also be treated in the physical- chemical plant for the separation or removal of water, or they can be treated biologically.

Physical-chemical treatment of inorganic wastes culminates with the production of two distinct effluent streams; the first stream contains concentrated or detoxified contaminants extracted from the incoming waste. This may be processed further prior to being disposed in a secure landfill. The second stream is a treated effluent which may be used for process purposes on site, or otherwise disposed of as further described below:

The various options that can be considered to dispose of treated effluent are:

- discharge into a receiving water body or sewer system
- evaporation
- deep well injection

A process flow diagram for a typical physical-chemical facility for the treatment of inorganic hazardous waste is set out on Figure 3.0-1 in Appendix "A."

The typical process consists of the following steps:

- Oxidation (for conversion of cyanide)
- Reduction (for conversion of hexavalent chromium to trivalent chromium)
- Neutralization and precipitation (for removal of heavy metals)
- Sedimentation (for separation of suspended solids)
- Pressure filtration (for concentration of solids)
- Solidification and stabilization (to condition solids for landfill)
- Vent gas cleanup (to control air emissions)

2.1.2 Oxidation

In a typical process sodium hypochlorite (NaOCl) is used to oxidize cyanide ions by converting them to carbon dioxide and nitrogen. The chemical reactions involved are:

$$2CN^- + 2OCl^- \rightarrow 2CNO^- + 2Cl^- \quad \text{(i)}$$

$$2CNO^- + 3OCl^- + H_2O \rightarrow 2CO_2\uparrow + N_2\uparrow + 2OH^- + 3Cl^- \quad \text{(ii)}$$

Thus the overall reaction is:

$$2CN^- + 5OCl^- + H_2O \rightarrow 2CO_2\uparrow + N_2\uparrow + 2OH^- + 5Cl^- \quad \text{(iii)}$$

Equipment consists of an agitated reactor vessel, a storage tank for sodium hypochlorite, a metering pump for addition of the oxidizing agent, an exchanger for cooling or heating and a pump for circulation through the exchanger and transfer from the reactor. Instrumentation includes pH measurement, measurement of oxidation-reduction potential (ORP), and level measurement.

Cyanide destruction by chemical oxidation (using sodium hypochlorite) can be carried essentially to completion within 2 hours if there are no interfering elements. However, certain transitional metal ions, such as iron, interfere with the alkaline oxidation of cyanides. If sufficient reaction time is allowed (24 hours) even these solutions can be treated successfully.

Although many oxidants can be used, alkaline chlorination is the method in most common use. Other cyanide destruction processes include (Grosse 1986 and Dawson 1986):

- ozonation
- electrolytic decomposition
- DuPont Kastone process which uses H_2O_2 and HCHO
- Polysulphide for high cyanide liquors (Ganczarczyk 1988)

2.1.3 Reduction

In the typical chemical reduction process sodium bisulfite ($NaHSO_3$) is used to convert hexavalent chromium to trivalent chromium. Chemical reduction of chromium is of interest because in its trivalent form chromium is less toxic and can be precipitated from solution for removal. The chemical reaction involved is:

$$4H_2CrO_4 + 6NaHSO_3 + 3H_2SO_4 \rightarrow 3Na_2SO_4 + 2Cr_2(SO_4)_3 + 10H_2O$$

In this reaction the oxidation state of chromium changes from 6^+ to 3^+ (chromium is reduced) while the oxidation state of sulfur increases from 2^+ to 3^+ (sulfur is oxidized).

Equipment consists of an agitated reactor vessel, a storage tank for sodium bisulfite, a metering pump for addition of the reducing agent, an exchanger for heating and cooling and a pump for circulation through the exchanger and transfer from the reactor. Instrumentation includes pH measurement, (ORP) measurement and level measurement.

The first step of the chemical reduction process is adjustment of the pH of the solution to be treated by the addition of sulfuric acid. This is followed by the addition of sodium bisulfite. Reaction times vary for different wastes, reducing agents, temperatures, pH's and concentrations. Usually reaction times are in the order of minutes; however, additional time is allowed to ensure complete mixing and reduction.

2.1.4 Neutralization and Precipitation

Waste is pumped from the oxidation reactor or from the reduction reactor into the Neutralization and Precipitation Reactor. Sulfuric acid is added to the alkaline stream from the oxidation reactor and calcium hydroxide is added to the acid stream from the reduction reactor so as to bring the pH into the range of 5.5 to 9.5. The reaction products include salts (from the neutralization reactions) and metal hydroxides (precipitated by the high pH). Precipitation refers to conversion of dissolved substances into insoluble ones. To meet the required effluent standards for Zinc, Cadmium and Mercury it will also be necessary to add sulfide after the pH is in the alkaline range. Some of the chemical reactions involved are:

Neutralization: $H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 + 2H_2O$ (i)

Precipitation: $NiSO_4\ 6H_2O + Ca(OH)_2 \rightarrow Ca(SO_4) + Ni(OH)_2 + 6H_2O$ (ii)

$ZnCl_2 + Na_2S \rightarrow ZnS\downarrow + 2NaCl$ (iii)

Equipment consists of an agitated reactor vessel, storage tanks for lime, sulfuric acid and sodium sulfide, an exchanger for cooling or heating the reactor and a pump for circulation of the reactor through the exchanger and transfer to the clarifier.

Reaction (iii) is an example of a precipitation type of reaction. Both zinc chloride and sodium sulfide are soluble in water; however zinc sulfide is only slightly soluble. Thus if an aqueous solution of the two compounds are mixed in the reactor a mixture of sodium ions, chloride ions and zinc sulfide particles results. This liquid/solid mixture is a suspension of solid ZnS in a saturated but dilute solution of ZnS. The concentration of zinc in solution is governed by the solubility product — a constant that is a function of temperature and pH.

Although lime is less expensive than other chemicals that could be used for neutralization and precipitation, it is more difficult to handle because of its limited solubility and scaling problems.

Some of the problems associated with the process of heavy metal removal by hydroxide precipitation are (Dawson 1986, Peters 1985 and National Lime Association):

- The gelatinous sludges formed have poor filterability characteristics.
- If the solution pH is changed, the hydroxide precipitate can redissolve.
- When several heavy metals are present in the waste, the pH that is most effective for one metal may not be effective for another metal.
- For some metals a high pH is required which means the water has to be neutralized after filtration.

- The presence of cyanides and complexing agents interfere with hydroxide precipitation.
- Chromium (vi) is not removed by hydroxide precipitation.
- The presence of SO_4 in the waste water results in large volumes of lime being required and in large volumes of insoluble $CaSO_4$ being formed.

2.1.5 Gravity Separation

Sedimentation is used to separate settleable solids resulting from precipitation reactions in the neutralization and precipitation reactor. Sedimentation is a physical process whereby particles suspended in a liquid are made to settle by means of gravitational force.

The effectiveness of sedimentation depends on the size of particles the gravity difference between them and the solution and whether the precipitate consists of discrete particles or is gelatinous. It is generally true that the larger the particles and the greater the gravity difference the more readily the particles settle. To assist in this process a flocculant or coagulant is added (polyelectrolyte). Polyelectrolyte materials are usually long chain water soluble polymers such as polyacrylamides.

Many precipitation reactions such as the precipitation of metals from solution by the addition of sulfide ions do not readily form floc particles but rather precipitate as very fine and relatively stable colloided particles. In such cases flocculating agents such as polyelectrolytes must be added to cause flocculation of the metal sulfide precipitates.

The type of clarifier used in this instance is a settling tank that provide 24 hour residence time for separation of solids from the aqueous solution. Polyelectrolyte flocculant is added to the water solids mixture as it is transferred from the neutralization and precipitation reactor into the settling tank.

The settled particles are then removed from the bulk of the liquid as a sludge containing from 2 to 5% solids with the balance being the liquid from which it is being separated.

Some wastes processed in these facilities contain ammonia and the chelating agent ethylene diamine tetra acetic acid (EDTA). In this event, pretreatment steps are required to remove ammonia and precipitate EDTA (as the free acid at low pH). Only after these steps are taken can metal precipitation take place.

2.1.6 Pressure Filtration

Sludge from the sedimentation process is pumped into a plate and frame filter press for de-watering.

The filter press consists of a collection of cloth covered plates arranged in parallel, held vertically within a frame, and pressed together by a hydraulic cylinder. Sludge is pumped under pressure into the chambers between the plates. Water exits through the filter cloth and concentrated solids are left behind in the chamber from which they are periodically removed. The filtrate is usually clear and can be discharged without further treatment. In this particular instance the filtrate is recycled back to the sedimentation unit (because of the low level of allowable suspended solids).

De-watering of flocculated sludge by pressure filtration can produce cake densities in the range of 40 to 50% dry solids using a one to two hour batch pressure cycle.

In some applications the medium is covered or precoated with a powdered filter-aid such as diatomaceous earth. This precoat material enables the removal of smaller particles. Lime and ferric chloride filter-aids are also frequently used in filter press applications to effect more complete removal of solids.

The intended product of the filter press is a de-watered sludge of typically 40 to 50% solids concentrations. The byproduct is a filtrate stream which can contain several hundred to several thousand milligrams per litre of suspended solids. This stream is recycled back to the sedimentation unit.

2.1.7 Solidification/Stabilization

Solidification/stabilization is used to reduce the mobility of pollutants in the environment thus making land disposal safer.

The following definitions are used herein:

Solidification is a term used collectively to define disposal techniques that convert a liquid, semi-solid, or finely divided solid particles into a solid **monolith** which is dimensionally stable.

Stabilization is a term to define a process which results in the improvement of some undesirable characteristic or property of the waste. It may change the material into a more stable form so that the waste will not undergo any further changes chemically, physically or biologically. It may render the toxic component in the waste insoluble or non-reactive.

Fixation refers to a treatment process which changes the nature of the waste physically and chemically to improve its resistance to leaching for final disposal.

Encapsulation is a process in which the waste materials are covered with a coating or a binding agent so that the waste materials are actually enclosed in a coating or a jacket of inert material.

Inorganic solidification/stabilization techniques include cement, lime and pozzolan-based techniques. These materials are usually mixed with aqueous sludges and proprietary additives to form a dry solid mass. Additives include kiln dust, soluble silicates and flyash. In the process being illustrated, lime and flyash are combined to form a pozzolan-type cementitious material. This inorganic solidification/stabilization technique is limited by organic content of the waste.

Solidification/stabilization processes are usually applied to residues which cannot be further treated before land disposal.

Generally, solidification/stabilization technology is effective for inorganic waste. Organic wastes generally cause problems that result in poor solidification/stabilization. The following table (Pojasek 1979) sets out the types of waste that are suitable for various solidification/ stabilization processes:

Process	Wastes Treated	Untreatable Wastes
Cement-based	Toxic inorganics Stack gas scrubber sludges	Organics Toxic Anions
Lime-based	Toxic inorganics Stack gas scrubber sludges	Organics Toxic Anions
Organic Polymer	Toxic inorganics	Acidic materials, organics, strong oxidizers
Thermoplastic	Toxic inorganics	Organics and strong oxidizers
Encapsulation	Toxic and soluble inorganics	Strong Oxidizers

Materials that are not readily solidified/stabilized include oils, greases, organic solvents, paint solvents and plastic compoents. A more detailed review of this matter is set out on Table 3-4 herein.

2.1.8 Vent Gas Cleanup

Purpose of the vent gas cleanup unit is to minimize emissions from the equipment in the physical-chemical processing plant. Particulate emissions from the flyash and lime storage silos are minimized by use of a particulate removal unit located on top of the storage silos.

All vent gas from various vessels and storage tanks in the physical- chemical plant is gathered through a negative pressure vent gas system and compressed from this lower pressure through an acid wash, an alkaline wash and an activated carbon unit (in sequence) before being vented to the atmosphere.

Liquid effluent from the acid and alkaline wash are processed and handled in the physical-chemical facility itself while the activated carbon waste is drummed and shipped to an incinerator facility for disposal.

2.1.9 Chemical Reactants Used

The reactants normally used for oxidation, reduction, neutralization, and precipitation vary from location to location depending on economics and availability. In a typical physical-chemical facility the following reactants are used:

Oxidation: Sodium hypochlorite (NaOCl) is used as a 10-11 wt% solution which is unloaded from tank trucks directly into storage.

Reduction: Sodium bisulfite ($NaHSO_3$) is used as a 38 wt% solution which is unloaded from tank trucks directly into storage.

Neutralization: To neutralize alkaline solutions 66°Be sulfuric acid (about 93 wt%) is used which is unloaded from tank trucks directly into storage.

To neutralize acid solutions use lime slurry of 10-15 wt% concentration made up from quicklime (CaO) or hydrated lime [$Ca(OH)_2$], either of which is received and stored as a finely pulverized solid.

Precipitation: Lime causes the bulk of heavy metals present to precipitate as the insoluble hydroxides; however to reduce concentrations of heavy metals even further,

sulfide ion is added as sodium sulfhydrate which is available as 44 – 46 wt% solution in tank trucks, or alternatively sodium sulfide (Na_2S) may be used depending on economics.

Chemical Fixation: Hydrated lime and flyash, or alternately Portland cement is mixed with water and the filter cake in a pug mill. If organics are present sodium silicate may be used.

The choice of reactants depends primarily on availability, cost, and process performance. While the reactants listed previously are typically used because they are readily available at reasonable cost and are adequate for the desired performance, other reactants that are sometimes used include the following (Dawson 1986):

Oxidation: Ozone, hydrogen peroxide, potassium permanganate, chlorine, chlorine dioxide and nitrous acid.

Reduction: Ferrous sulfate, sodium bisulfite, sulfur dioxide and sodium borohydride.

Neutralization: Limestone, sodium hydroxide, soda ash, hydrochloric acid, waste acids and waste alkalis.

Precipitation: Sodium sulfide, sodium hydrosulfide, iron (ferrous) sulfide and sodium carbonate.

Chemical Fixation: Organic techniques include chemical grouts, thermo-plastics, organic polymers and glassification. Thermo-plastics use materials such as bitumen, asphalt, paraffin or polyethylene. Organic polymers include urea-formaldehyde, polyester resins or polyvinyl chloride.

Inorganic techniques utilize cement kiln dust, soluble silicates, flyash and blast furnace slag.

2.2 Biological Treatment:

2.2.1 General

Biological treatment processes are applicable to aqueous waste streams containing organic contaminants. Use of a pretreatment process such as chemical treatment to precipitate heavy metals or U.V. catalyzed oxidation to destroy some organic compounds can be employed to enhance biological degradation. In these processes, the organic material is used as a substrate for microbial growth, resulting in the decomposition of the organics. Inorganic contaminants present in the waste are not treated by biological processes, and as a result are present in the sludge or effluent discharges. The presence of water is essential for all biological treatment processes. Oxygen is also required for aerobic treatment, enabling these processes to decompose both simple and complex organic compounds. Anaerobic processes, due to the absence of oxygen, may only decompose simple organics such as carbohydrates, proteins, alcohols, and acids.

Several factors affect the level of treatment achievable with biological processes. These include:

The type of organic contaminant. Some organics, such as pesticides, are not readily decomposed by microbial action.

The concentration of the contaminant. If a contaminant is present in low concentrations, it may not be capable of supporting a microbial population. High concentrations may be toxic to bacteria. These levels depend on the type of organic contaminant.

The presence of inhibitors. Not only are inorganics not treated by biological processes, but the presence of some inorganics may even inhibit microbial action. Some organics may also have this effect.

The extent of acclimatization. Bacterial populations must become acclimatized to a waste type in order to achieve suitable treatment efficiencies. Long acclimatization periods increase a microbial population's ability to decompose a waste. Short acclimatization periods or sudden changes in the characteristics of a waste decrease the treatment efficiency.

Reaction times. The period of time that the waste is in contact with the microbial population determines the level of treatment. Reaction times, or residence times, must be optimized depending on the type of contaminant and its concentration.

Table 2-1 — Summarizes the types of organic compounds which may be reduced through biological treatment, either aerobic or anaerobic. The rate or ease of biodegradation varies depending on the type of compound. For example, pesticides and herbicides are listed as being treatable by both anaerobic and aerobic processes; the rate of biodegradation, however, is often too slow to be useful in most applications.

Table 2-2 — Gives examples of various chemicals and the concentrations at which they become difficult to treat using biological processes. Values are presented for the compound where it is the sole carbon source, and for the compound where it is present with other organic compounds. From these examples, it can be seen that some moderate and low concentrations of hazardous organic compounds are biodegradable, but that often moderate to high concentrations become toxic to the microbial population. This latter case is increased by the presence of other organic compounds.

Several biological treatment processes have been developed and applied to municipal and industrial wastes. Of these, some are also potentially applicable to hazardous wastes. A brief discussion of generic biological treatment processes which may be applied to hazardous wastes follows.

2.2.2 Activated Sludge

Activated sludge treatment is probably the optimum proven technology for biodegradation of organics in an aqueous waste stream. It is a relatively low cost system, employing no chemicals except for additive nutrients, pH adjustment and coagulant aids, should any of these be required. Energy is primarily required for the maintenance of aerobic conditions. Essentially the process consists of contacting the organics in the wastewater with microorganisms and oxygen from the air, followed by solids-liquid separation. This separation allows the collection and recycling of most of the microorganisms to the contactor, as well as the clarification of the

wastewater. A blowdown stream of excess sludge is removed from the system. The recycling of microorganisms is the unique aspect of the activated sludge process.

TABLE 2-1

SUMMARY OF ORGANIC GROUPS SUBJECT TO BIODEGRADATION

Substrate Compounds	Respiration	
	Aerobic	Anaerobic
Straight Chain Alkanes	*	*
Branched Alkanes	*	*
Saturated Alkyl Halides		*
Unsaturated Alkyl Halides	*	*
Esters, Glycols, Expoxides	*	*
Alcohols	*	*
Aldehydes, Ketones	*	*
Carboxylic Acids	*	*
Amides	*	*
Esters	*	*
Nitriles	*	*
Amines	*	*
Phthalate Esters	*	*
Nitrosamines		*
Cyclic Alkanes	*	
Unhalogenated Aromatics	*	*
Halogenated Aromatics	*	*
Simple Aromatic Nitro Compounds	*	*
Aromatic Nitro Compounds with Other Functional Groups	*	*
Phenols	*	*
Halogenated Side Chain Aromatics	*	
Fused Ring Hydroxy Compounds	*	
Nitrophenols		*
Halophenols	*	
Phenols — Dihydrides, Polyhydrides	*	
Two & Three Ring Fused Polycyclic Hydrocarbons	*	
Biphenyls	*	
Chlorinated Biphenyls	*	
Four Ring Fused Polycyclic Hydrocarbons	*	
Fused Polycyclic Hydrocarbons	*	
Organophosphates	*	*
Pesticides and Herbicides	*	*

Source: Envirosphere, 1985, as Cited in EPA, 1985

TABLE 2-2

PROBLEM CONCENTRATIONS FOR BIOLOGICAL TREATMENT OF SELECTED CHEMICALS

Chemical	Problem Concentration (mg/l)	
	Substrate[1] Limiting	Non-Substrate[2] Limiting
n-Butanol	—	>1000
sec-Butanol	—	>1000
t-Butanol	>1000	>1000
Allyl alcohol	—	>1000
2-Ethyl-1-hexanol	500-1000	—
Formaldehyde	—	50-100
Crotonaldehyde	200	50-100
Acrolein	—	—
Acetone	—	>1000
Methyl isobutyl ketone	>1000	>1000
Isophorone	>1000	—
Diethylamine	—	300-1000
Ethylenediamine	—	100-300
Acrylonitrile	>1000	100
2-Methyl-5-ethylpyridine	>1000	100
N,N-dimethylaniline	>1000	—
Phenol	>1000	300-1000
Ethyl benzene	>1000	—
Ethyl acrylate	600-1000	300-500
Sodium acrylate	—	>500
Dodecane	>1000	—
Dextrose	>1000	>1000
Ethyl acetate	>1000	—
Ethylene glycol	>1000	>900
Diethylene glycol	—	>1000
Tetraline	1000	—
Kerosene	—	>500
Cobalt chloride	—	>1000

(1) Substrate limiting represents the condition in which the subject compound is the sole carbon and energy source.

(2) Non-substrate limiting represents the condition in which other carbon and energy sources are present.

Source: SCS Engineers, 1979, as cited in EPA, 1985

There are four types of activated sludge processes: standard (the most common), extended aeration, high rate and oxygen activated sludge. The extended aeration process is characterized by a lower organic loading (or food to microorganism ratio) than the standard process. This generally means longer contactor retention times (larger aeration basins for the same flows), but it has the advantage of producing less excess sludge for disposal (about half of that produced by the standard process). It is usually applicable to relatively small wastewater flows. The high rate process is characterized by low contactor retention time, lower effluent quality, higher excess sludge production, but lower overall cost (exclusive of sludge disposal). In the oxygen activated sludge process, relatively pure oxygen (90% or greater O_2 content) is used for aeration instead of air. This results in a reduction in aeration basin size and the number of aerators. Offsetting the resulting cost saving is the cost of an air separation unit to produce the oxygen. The complexity of the process is also increased. Advantages claimed are better control of dissolved oxygen content, and better sludge settling which permits a higher sludge concentration in the contactor.

The large microbial population available in activated sludge systems permit the acclimatization to various waste types and allow for higher BOD loadings. Effluent from these systems requires treatment for residual organics, salts, and suspended solids, often achieved with filtration and/or activated carbon.

2.2.3 Activated Sludge with Powdered Activated Carbon

The operating principles of these systems are essentially the same as with conventional activated sludge processes, with the exception that powdered activated carbon (PAC) is included with the microbial sludge. Reductions in effluent BOD, COD, total organic carbon, and suspended solids have been reported. In addition, the PAC provides a buffer against shock loadings, and often eliminates the need for an activated carbon filtration step for the effluent.

2.2.4 Sequencing Batch Reactors

Similar in concept to the activated sludge systems, sequencing batch reactors (SBR's) perform all of the process stages in one vessel. Four stages are involved, including:

- Fill stage, where the reaction vessel is filled with the waste to be treated.
- Mix stage, where the microbial population sludge is mixed and aerated with the waste.
- Settle stage, where the microbial population sludge settles to the bottom of the reactor.
- Drain stage, where the effluent is removed and the sludge is retained.

The process cycles in a batch manner, and has similar benefits and requirements as the activated sludge systems. Increased operational flexibility, however, is available. Reaction times may be varied to accommodate heavy loadings or wastes with low biodegradability. Settling times and tank volumes may also be adjusted. Contaminant concentrations may be monitored to ensure satisfactory effluents.

2.2.5 Trickling Filter

This is not actually a filter, but is a bed of plastic or rock packing or other support media, on which bacterial slime can grow. Wastewater is sprayed over the top of the bed and trickles down over the bacterial slime, resulting in decomposition of the organic compounds, and nourishment of the bacteria. Aeration is by natural or forced draft. Trickling filters are relatively inefficient in BOD (biochemical oxygen demand) removal compared to activated sludge systems, but have a greater tolerance for shock loads. They are sometimes used as preliminary roughing units upstream of activated sludge systems. A clarifier is needed downstream of the trickling filter to remove sloughed slime from the wastewater. Energy requirements are low.

2.2.6 Rotating Biological Contactor (RBC)

This is a more recent development which operates on the same principle as the trickling filter. In this case the bacterial slime grows on the surface of a series of slowly rotating vertical discs (or other media) attached to a central shaft, which are partially submerged in the contaminated wastewater. Hence the slime alternately contacts the air and the organics in the wastewater, resulting in the same decomposition of organics and nourishment of bacteria that takes place in the trickling filter. The sloughed slime is also removed from the wastewater in a clarifier. Energy requirements are also low, and performance is comparable to activated sludge systems. RBC's have replaced activated sludge units and trickling filters in some installations, presumably on the basis of economics.

2.2.7 Fluidized Bed Contactor

In these systems, pre-oxygenated waste water is circulated through a bed of sand or similar media covered with microbial growth. The flow of wastewater is in an upward direction through the media bed, resulting in the suspension of particles and the maximization of the available surface area. Biodegradation occurs through contact between the bacteria and the organic contaminant in the presence of oxygenated water. As these systems maintain a large bacterial population within a small reactor volume, they operate best with high organic loadings. In order to maintain a healthy bacterial population, a constant feed rate is also desirable.

The types of waste treatable by fluidized bed contactors are similar to other biological treatment systems, although they are capable of handling higher concentrations of organics. Fluidized bed contactors commonly achieve high percent reductions in BOD, but as they accept high concentrations initially, the effluent often requires further treatment to meet water quality criteria. As with other biological systems, the efficiency of these systems is dependent on several factors. Operational flexibility is limited for fluidized beds, and therefore they are best suited to constant, high loadings of a readily biodegradable nature.

2.2.8 Aerated Lagoons/Waste Stabilization Ponds

Waste stabilization ponds, also referred to as lagoons or oxidation ponds, are shallow (0.6 to 1.2 M) ponds which passively aerate waste water through wave action. Aerobic biodegradation occurs, releasing carbon dioxide, which in turn is consumed by algae generating more oxygen for further biodegradation. As it is a passive system, long retention times (up to 30

days) are required, and only wastes of low BOD are adequately treated. These systems may be operated on a batch or continuous basis.

Aerated lagoons are typically deeper than stabilization ponds, and aeration is supplied through diffusers or surface aerators operated mechanically. As a result, retention times are often in the neighborhood of three or four days, and less algae is present. Aerated lagoons differ from activated sludge in that no sludge or microbial growth is recycled from the effluent. Treatment efficiencies in aerated lagoons are not as high as in activated sludge systems, and retention times must be longer.

Neither aerated lagoons nor waste stabilization ponds can accept as high an organic loading as activated sludge systems can, due to the smaller microbial population. Also, shock loadings and variable wastes are not handled as well in these systems, for the same reason. As these systems operate outdoors, the lower winter temperatures decrease treatment efficiency. Lagoons are best suited to low organic loadings in applications where plenty of land is available, and shock loadings or variable wastes are not expected.

2.2.9 Anaerobic Digestion

In an oxygen-free environment, anaerobic and facultative bacteria biodegrade organic wastes. Various configurations exist which may be used for wastes of different concentrations, and characteristics. Anaerobic systems operate with high strength wastes such as sludges, and generate a usable fuel product in methane gas.

Anaerobic digestors require acclimatization to the waste type, and as such they are not well suited to varying wastes. Biodegradation is inhibited by some metals and organics to a greater extent in anaerobic digestors than in aerobic systems, limiting the applicability of the systems to non-metallic, simple organics of suitable concentrations. Variations in flow are poorly handled, as too little or too great a flow stops the process. Shock loads similarly can be destructive.

2.2.10 Aerobic Digestion

This is also a sludge stabilization process, to reduce the volume and BOD content of sludges prior to further processing and/or disposal. Aerobic digestion of excess activated sludge may be considered to be a continuation of the activated sludge process at a low food to microorganism ratio. Retention times vary from 10 to over 20 days. Since it is carried out in open tanks, it is not particularly suitable for operation in cold climates.

2.2.11 Composting

This is another sludge stabilization process which can handle feed sludges with up to 50 percent solids content. It is a type of aerobic digestion which is relatively insensitive to toxicants and adsorbs metals. It is the highest cost sludge stabilization process, but is less costly than incineration. Sludge is piled on the ground in windrows, usually with added wood chips. Fresh sludge can be sprayed on top. The piles are aerated by periodic turning using earth moving equipment. Complete digestion of most organic waste takes place in three to four months. Refinery wastes and difficult organics may take a year. Cold weather would lengthen these times.

2.2.12 Land Application

Also referred to as land treatment or land farming, this form of biological treatment taking advantage of the natural assimilative capacity of soils. Wastes are spread on to the land surface, where they infiltrate or are cultivated into the soil. Biodegradation occurs due to the presence of naturally occurring bacteria. Other contaminants are adsorbed by soil particles, volatized through contact with the air, or transformed physically or chemically. Land application has the advantage of leaving no residues, as both liquids and sludges may theoretically be applied to land.

The ability of the soil and the natural microbial population to assimilate the wastes is dependent on many factors, including:

- Contaminant type, presence of inhibitors, the contaminant concentration, and other factors common to biological systems.
- The soil type and texture
- Soil Infiltration rates
- Soil conditions, such as pH, temperature, moisture level, and nutrient concentrations (nitrogen and phosphorus in particular)
- Soil depth, groundwater level, surface slope

The maximum rate of application of waste depends on all of these factors, and as a consequence, monitoring of contaminant concentrations, soil moisture, and groundwater should be performed. Surface runoff must be monitored and controlled.

Problems with land application include odours due to the volatilization of some compounds, and public perception of the practice. Phytotoxicity is also a concern for some wastes. As microbial activity is a function of temperature, treatment efficiencies and therefore application rates vary. Frozen soil, snow cover, and saturated soil are all conditions which prevent any land application of wastes, and therefore decrease the reliability of this treatment option.

2.3 Current Practice:

Current practice at three European and one U.S. physical-chemical treatment facilities is cited as follows:

HIM, Frankfurt, West Germany — this is a complete physical-chemical plant for handling inorganic wastes of acids, bases, cyanides, etc. (over 4,000 different materials). Process consists of receiving into underground tanks, storage tanks, reactors, feed tanks, filters, liquid holding tanks, sludge containers, and chemical feed tanks. Plant runs five days per week, eight hours per day. Every container received is sampled and analyzed before accepting. Checks are made for pH, cyanides, hexavalent chromium, heavy metals, and oil content. Neutralized effluent liquids meeting government specifications are disposed via sewer to municipal biological treatment plant.

Batch reactions are primarily manually controlled. Treatment chemicals used are lime, sodium bisulfite, ferric chloride, sodium hypochlorite, ferrous chloride, hydrochloric acid and sodium sulfide. Vent gases are treated with acid wash, alkali wash and activated carbon.

Kommunekemi (Chem Controls), Nyborg, Denmark — this is a complete hazardous waste treatment facility including incineration and landfill, as well as physical-chemical treatment. All physical-chemical treatment is carried out in one reactor, on an alternating basis. The reactor is a horizontal square concrete tank, tile-lined (experiences inadequate mixing in corners). Treatment of wastes is determined by chemical engineer, on the basis of manifest and lab analysis. Receiving and phys/chem operates 40 hours per week, incinerator operates continuously.

No analysis is done before acceptance of waste. This is done after the material is received and mixed in storage. Effluent water is analyzed for TOC, pH, conductivity, turbidity, and temperature.

Treatment chemicals used include sulfuric acid, sodium hypochlorite, sodium sulfide, hydrochloric acid (to regenerate BFW treatment units), caustic soda, lime and ferrous sulfate.

Ekokem, Riihimaki, Finland — this is also a complete hazardous waste treatment facility, including incineration and landfill, as well as physical-chemical treatment. It is a more highly automated facility than the German or Danish plants. Receiving and phys/chem operates 40 hours per week, incineration is continuous. The laboratory group prepares treatment recipes for the operators.

Waste is received and accepted based on the manifest composition. It is sampled and analyzed after unloading.

Chemical Waste Management, Kettleman Hills, California — this is primarily a hazardous waste landfill facility, however some physical- chemical treatment is done. Inorganic solutions and slurries of acids, bases and heavy metals are neutralized, and heavy metals precipitate by the addition of lime in solar evaporation ponds. Solids accumulate and once a year are removed and placed in landfill (economically efficient).

Lime is used for neutralization. Calcium polysulfide is used to detoxify cyanide. Cement dust and fly ash are used for stabilization.

In addition to the above described facilities, at least two hazardous waste treatment facilities in the U.S. employ activated sludge biological treatment. Hyon Waste Management Services, Inc. operates a continuous activated sludge system, while a batch activated sludge treatment is used at Bio-Ecology Systems, Inc.

Guideline 2-2: Preference should be given to technologies and process systems that produce the lowest quantity of residues and that can detoxify and concentrate residual contaminants removed from the waste to the greatest extent. Preference should also be given to technologies which produce residues:

- **requiring minimum further treatment prior to disposal,**
- **which are most amiable to subsequent treatment,**
- **which can be readily rendered both physically and chemically stable by the solidification process prior to landfilling.**

3.0 EFFECTIVENESS OF THE TREATMENT PROCESSES

3.1 General:

A wide variety of physical, chemical and biological treatment processes have been applied to hazardous waste streams, with varying effectiveness. Pollutant removability and treatability depends on many factors, as discussed in the previous sections, most notably:

- **Concentration of Pollutants** — Often the efficiency of a waste treatment process is reported as the percent of influent contaminant removed during the process. Thus, influents with large concentrations of contaminants may have a high treatment efficiency in a particular process, but still result in effluents with significant contamination. Other concerns are toxic concentrations of contaminants in wastes designated for biological treatment, and excessive volumes of conditioners or additives required for some physical or chemical treatment processes.

- **Waste Stream Composition** — Many, if not all, hazardous waste streams are composed of multiple contaminants. Waste treatment processes, conversely, are frequently monitored for their ability to remove or treat only a few specific contaminants, and other contaminants that may be present are not reported on. The effect of these additional contaminants on the treatment efficiencies of those contaminants of concern can be considerable, either enhancing or decreasing performance.

- **Operating Characteristics** — Every treatment process has different degrees of flexibility in operation. Flexibility is required to accommodate wastes which vary in concentration, composition, and general treatability. The ability of a treatment process to alter residence times, recycle rates, and other operating characteristics affects the level of treatment achievable in the process.

Due to these generalized considerations, the effectiveness of treatment processes as reported in the literature varies greatly, even for similar wastes in similar treatment processes. A further consideration is that these treatment operations are frequently individual stages in a larger program comprising several treatment steps. The effectiveness of a single stage in the treatment process is a function of any preceding treatment processes. Therefore, direct comparisons of treatment efficiencies as reported in case studies are not always applicable, and treatment efficiencies estimated in laboratory processes may not be representative of actual situations. Overall treatment efficiencies may only be accurately estimated for specific waste streams of known composition in a known treatment program.

This being said, there is value in reviewing the levels of treatment achieved in existing hazardous waste treatment processes. Waste compatibility with a process, as well as rough estimates of the treatment efficiency of the process, may be determined in this manner. This information simplifies the selection of appropriate treatment processes for a waste stream. It is important, however, to keep in mind the limitations of the data when reviewing treatment efficiencies. The highest treatment efficiencies represent situations in which all parameters favour the removal of the contaminant; lower treatment efficiencies represent situations in which waste

stream characteristics or operating methods affect the level of removal. Specific applications of the waste treatment processes discussed may fall any where within this range, and case-specific studies are necessary to obtain more than a rough estimate of the treatment efficiency.

Appendix "D" summarizes the range of treatment efficiencies reported for individual pollutants by a variety of physical, chemical, and biological treatment methods. In the following sections, treatment efficiencies for typical processes applied to representative wastes are presented and discussed. For more extensive summaries, reference should be made to: Martin and Johnson, 1987; Shuckrow et al, 1981; Monenco Ltd., 1986; and Patterson et al, 1981.

3.2 Physical-Chemical Treatment:

Physical and chemical treatment processes have proven effective in the treatment of most inorganic and many organic wastes. Wastes containing metals, acids, caustics, anions, aqueous organics, in the form of liquids, solids, or sludges are frequently treated by physical or chemical processes and substantial reductions have been achieved.

Metal contaminants are particularly suited to physical and chemical treatment processes. Dissolved salts of metals may be removed through various membrane or filtration processes, or through altering the chemical equilibrium of the waste stream. Table 3-1 summarizes treatment efficiencies for several metal wastes as reported in the literature. In this and other tables in this chapter, the treatment efficiencies are reported as a range of values. Waste streams of appropriate composition or which have undergone suitable pretreatment should be near the top end of the range, while contaminants present in other, less suitable waste streams should be removed to a lesser degree. The highest treatment efficiency, therefore, represents the optimal treatment conditions.

Four treatment processes are shown in Table 3-1, all of which are capable of high removal efficiencies for metals. Precipitation and sedimentation processes, under optimal conditions, have been shown to remove virtually all metal contaminants from a waste stream with very high treatment efficiencies. Other processes, such as reverse osmosis, work well on most metals but may have trouble attaining 99 or 100 percent removal for others. In all cases, extremely poor removal efficiencies have also been reported in the literature, due most likely to the presence of interfering contaminants in the waste, or to improper operating conditions of the processes.

TABLE 3-1

EXAMPLE REMOVAL/TREATMENT EFFICIENCIES OF SOME PHYSICAL-CHEMICAL TREATMENT PROCESSES FOR METALS

Metal	Removal/Treatment Efficiency			
	Chemical Precipitation/ Sedimentation	Activated Carbon	Filtration	Reverse Osmosis
Antimony	28 to 99%	0 to 33%	0 to 99%	10 to 60%
Arsenic	20 to 99%	0 to 99%	0 to 99%	57 to 99%
Beryllium	33 to 99%		0 to 7%	85%
Cadmium	0 to 99%	6 to 95%	0 to 99%	0 to 99%
Chromium	13 to 99%	3 to 97%	0 to 99%	3 to 98%
Copper	0 to 100%	0 to 99%	0 to 99%	0 to 100%
Iron	26 to 99%	45 to 68%		100%
Lead	0 to 99%	2 to 93%	3 to 99%	0 to 100%
Mercury	6 to 98%	0 to 99%	0 to 89%	0 to 60%
Nickel	0 to 100%	4 to 68%	0 to 99%	9 to 97%
Selenium	0 to 99%	0 to 96%	0 to 10%	67 to 85%
Silver	0 to 99%	12 to 36%	0 to 91%	0 to 92%
Thallium	30 to 99%	84%		50 to 99%
Zinc	1 to 100%	5 to 99%	0 to 99%	31 to 100%

Source: Patterson, J.W.

Physical-chemical treatment processes for anions and other non-metallic inorganic wastes are also well established. Unlike metals, no single process achieves uniformly high removal efficiencies for all of these wastes, as the properties of the different wastes can vary considerably. Table 3-2 summarizes several treatment efficiencies reported in the reduction of cyanide wastes by different processes. Chemical processes such as oxidation achieve the highest removals reported in the literature, often resulting in 100 percent removal. Suitable applications of physical-chemical treatment processes may result in similarly large removals for other anions as well.

TABLE 3-2

TREATMENT EFFICIENCIES FOR CYANIDE IN PHYSICAL-CHEMICAL TREATMENT PROCESSES

Treatment Process	Percent Removal
Activated Carbon Adsorption	
- granular	1 to 90%
- powdered	50 to 69%
Chemical Oxidation	
- chlorination	86 to 100%
- ozonation	33 to 100%
Coagulation and Flocculation	60%
Electrolysis	98 to 100%
Filtration	0 to 99%
Flotation	0 to 62%
Oil Separation	13%
Reverse Osmosis	23 to 91%
Sedimentation	20 to 90%

Source: Patterson, J.W.

Many organic wastes may also be effectively treated in physical-chemical treatment processes. Gravity separation, or other phase separation processes such as centrifugation, may be used to remove oils and other immiscible organics from an aqueous waste. Many adsorption processes are also applicable to organics, in particular carbon adsorption. Treatment efficiencies for organic compounds vary with the type and concentration of contaminant as well as with the treatment process. An example of the level of treatment achieved by various physical-chemical processes is shown in Table 3-3 for phenol. Very high treatment efficiencies have been reported for this and other organic contaminants by various physical or chemical treatment processes.

TABLE 3-3

TREATMENT EFFICIENCIES FOR PHENOL IN PHYSICAL-CHEMICAL TREATMENT PROCESSES

Treatment Process	Percent Removal
Activated Carbon Adsorption	
- granular	18 to 97%
- powdered	93 to 99%
Chemical Precipitation/Sedimentation	
- alum	8 to 100%
- lime	0 to 99%
- ferric chloride	33%
- other precipitants	33 to 99%
Coagulation and Flocculation	0 to 91%
Filtration	0 to 100%
Flotation	0 to 94%
Oil Separation	0 to 100%
Reverse Osmosis	5 to 80%
Sedimentation	0 to 100%
Solvent Extraction	3 to 100%
Ultrafiltration	27%

Source: U.S. EPA, Hazardous Waste Treatment Technology, 1986

Tables 3-1, 3-2 and 3-3 show physical-chemical treatment processes to be capable of very high removal efficiencies for many waste types. One treatment process not discussed so far is solidification/stabilization. As these processes do not remove a contaminant so much as isolate it, removal efficiencies are not really applicable. Rather, it is of more use to discuss the compatibility of a waste with a solidification or stabilization technique; if a waste is compatible, the treatment should be effective. Table 3-4 summarizes the compatibility of various processes with certain waste categories. For all inorganic waste types, there is at least one established solidification or stabilization process which may be compatible (depending ultimately on the characteristics of the specific waste stream to be treated). For solid organics, some processes are also effective, but for organic solvents and oils, no processes are suitable.

It is not possible within the scope of this report to discuss the effectiveness of all physical and chemical treatment processes and all types of waste streams. From those examples that are discussed here, it may be seen that physical-chemical treatment is capable of very effective treatment of most waste types, but that these same processes may also result in very little removal of contaminants if conditions are not favourable.

Guideline 3-1: Careful matching of waste type and treatment technology, coupled with pilot scale tests to ascertain optimal operating conditions, is required to achieve high levels of treatment efficiency through the physical-chemical-biological treatment processes.

TABLE 3-4

COMPATIBILITY OF WASTE CATEGORIES

WITH SOLIDIFICATION/STABILIZATION TECHNIQUES

Waste Component	TREATMENT TYPE: Cement Based	Lime Based	Thermoplastic	Organic Polymer (UF)[a]	Surface Encapsulation	Self-Cementing	Classification and Synthetic Mineral Formation
Organics							
1. Organic solvents and oils	Many impede setting may escape as vapor	Many impede setting, may escape as vapour	Organics may vaporize on heating	May retard set of polymers	Must first be absorbed on solid matrix	Fire danger on heating	Wastes decompose at high temperatures
2. Solid organics (e.g. plastics, resins, tars)	Good-often increases durability	Good-often increases durability	Possible use as binding agent	May retard set of polymers	Compatible-many encapsulation materials are plastic	Fire danger on heating	Wastes decompose at high temperatures
Inorganics							
1. Acid wastes	Cement will neutralize acids	Compatible	Can be neutralized before incorporation	Compatible	Can be neutralized before incorporation	May be neutralized to form sulfate salts	Can be neutralized and incorporated
2. Oxidizers	Compatible	Compatible	May cause matrix breakdown, fire	May cause matrix breakdown	May cause deterioration of encapsulating materials	Compatible if sulfates are present	High temperatures may cause undesirable reactions
3. Sulfates	May retard setting and cause spalling unless special cement is used	Compatible	May dehydrate and rehydrate, causing splitting	Compatible	Compatible	Compatible	Compatible in many cases
4. Halides	Easily leached from cement, may retard setting	May retard setting, most are easily leached	May dehydrate	Compatible	Compatible	Compatible if sulfates are present	Compatible in many cases
5. Heavy metals	Compatible	Compatible	Compatible	Acid pH solubilizes metal hydroxides	Compatible	Compatible if sulfates are present	Compatible in many cases
6. Radioactive material	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible if sulfates are present	Compatible

Source: Guide to the Disposal of Chemically Stabilized and Solidified Waste, U.S. EPA, Report #SW-872, September 1980 as cited in Martin & Johnson, 1987.

[a] Urea-formaldehyde resin.

3.3 Biological Treatment:

The effectiveness of biological treatment is dependent on the ability of microbial populations to degrade a waste. Operating parameters such as acclimitization periods and residence times, as discussed previously, may be adjusted to optimize this treatment for many waste types. Some wastes, however, are not biodegradable and will not be removed in this manner. Many biological treatment processes may achieve some removal of these compounds through adsorption of the contaminant on to the microbial floc, which is removed with the sludge. Metal contaminants are removed in this manner at varying levels of effectiveness, as shown in Table 3-5. Biological treatment processes which support large bacterial populations, such as activated sludge and fixed media processes, should be capable of adsorbing significant amounts of metals, and achieving removal efficiencies of up to 99 percent. The toxicity of concentrated metals to bacterial growth, however, limits the application of this form of treatment to low concentrations of metals. In addition, the metals must be contained in a waste stream of a suitable organic nature to support the microbial growth.

Other inorganic wastes, such as acids and caustics, are often immediately toxic to bacteria, and are not treated or removed in any degree. Some highly toxic wastes, such as cyanide, are treatable in biological systems if introduced in suitably dilute concentrations. In general, however, biological treatment is most effective for wastes which may be biodegraded by the bacterial growth, namely organic wastes. Even then, some organic wastes are not biodegradable within the time frame allotted by most biological treatment systems. Other organics may be toxic to bacteria in certain concentrations, or may not be treatable due to the presence of other contaminants.

Table 3-6 summarizes treatment efficiencies for ten selected organic contaminants and five treatment processes, as reported in the literature.

TABLE 3-5

REMOVAL EFFICIENCIES OF METALS IN BIOLOGICAL TREATMENT PROCESSES

Metal	Removal/Treatment Efficiency		
	Activated Sludge	Rotating Biological Contactor	Aerated Lagoon
Antimony	33 to 90%		
Arsenic	0 to 98%		99%
Beryllium			50%
Cadmium	0 to 99%	96%	44 to 97%
Chromium	5 to 98%	98%	0 to 99%
Copper	2 to 99%	97 to 99%	21 to 94%
Iron	59%		
Lead	10 to 99%	56%	0 to 99%
Mercury	26 to 94%	71%	0 to 99%
Nickel	0 to 99%	92%	0 to 72%
Selenium			50 to 99%
Silver	3 to 99%	47%	0 to 63%
Zinc	0 to 99%	81 to 98%	34 to 99%

Source: Shuckrow et al

TABLE 3-6

REMOVAL EFFICIENCIES OF SELECTED ORGANIC CONTAMINANTS IN BIOLOGICAL TREATMENT PROCESSES

	Removal/Treatment Efficiency				
Organic Pollutant	**Activated Activated Sludge**	**Rotating Sludge with PAC**	**Trickling Filter**	**Biological Contactor**	**Aerated Lagoon**
Benzene	60 to 100%	95 to 100%	92%	96%	0 to 96%
Carbon Tetrachloride	98%	94%			
Chloroform	5 to 99%		0 to 78%	97%	0 to 99%
Di-n-butyl Phthalate	60 to 99%		25%		0 to 99%
Ethylbenzene	69 to 99%	78 to 84%	87%	95%	72 to 97%
Methylene Chloride	0 to 72%		0 to 96%	99%	65 to 99%
Phenol	8 to 100%	83 to 96%	0 to 91%	99%	0 to 71%
Tetrachloroethylene	0 to 99%	88%	92%	98%	60 to 99%
Toluene	17 to 100%	79 to 100%	98%	100%	90 to 99%
Trichloroethylene	56 to 99%	90%	0 to 96%	99%	0 to 92%

Source: Shuckrow et al

The facilities reporting these treatment levels are both publicly owned and industrial facilities. In a study of solely publicly owned treatment works in the U.S., the EPA monitored a variety of organic pollutants and some metals. Table 3-7 summarizes the findings of this study, with the treatment efficiencies shown as an average rather than a range of values (possible in this case as all data comes from similar facilities and was collected by the same source). These results show similar, high efficiencies for volatile organics and varying treatment levels for other organics. The removal efficiencies achieved by activated sludge processes are generally the highest, with aerated lagoons being the lowest overall. The most significant differences are seen in metals removal, where aerated lagoons perform poorly, for reasons already discussed.

TABLE 3-7

AVERAGE REMOVAL EFFICIENCIES FOR SELECTED CONTAMINANTS IN PUBLICLY-OWNED TREATMENT WORKS IN THE UNITED STATES

Activated Pollutant	Pure O_2 Sludge	Aerated System	Trickling Lagoon	Filters	RBCs[2]
Volatile Organics					
benzene	(10) 77	(2) 87	(0) -	(1) 92	(0) -
chloroform	(20) 62	(3) 50	(0) -	(4) 69	(0) -
ethylbenzene	(10) 90	(3) 86	(1) 83	(4) 89	(0) -
methylene chloride	(14) 48	(3) 34	(1) 96	(4) 32	(0) -
tetrachloroethene	(20) 82	(3) 75	(1) 91	(4) 62	(1) 50
toluene	(21) 93	(3) 99+	(1) 89	(4) 93	(1) 99+
trichloroethene	(20) 90	(2) 67	(1) 97	(4) 95	(1) 67
1,1,1-trichloroethane	(17) 88	(3) 80	(1) 91	(3) 91	(0) -
trans-1,2-dichloroethane	(19) 80	(2) 85	(1) 88	(0) -	(0) -
Acid Extractable Organics					
phenol	(15) 89	(3) 99+	(1) 50	(3) 94	(1) 99+
Base-Neutral Extractable Organics					
bis (2-ethylhexyl) phthalate	(8) 62	(3) 64	(1) 23	(4) 72	(1) 86
butyl benzyl phthalate	(2) 94	(3) 84	(1) 93	(1) 93	(0) -
di-n-octyl phthalate	(6) 68	(1) 98	(1) 50	(3) 50	(0) -
diethyl phthalate	(2) 91	(0) -	(0) -	(0) -	(0) -
naphthalene	(6) 92	(1) 70	(0) -	(0) -	(0) -
Metals					
cadmium	(6) 85	(2) 83	(1) 44	(2) 84	(0) -
chromium	(22) 84	(3) 76	(1) 49	(4) 63	(0) -
copper	(22) 84	(3) 92	(1) 21	(4) 75	(1) 97
lead	(2) 82	(1) 97	(1) 0	(0) -	(0) -
mercury	(8) 76	(3) 83	(1) 0	(2) 49	(0) -
nickel	(15) 34	(2) 18	(1) 14	(4) 0	(0) -
silver	(5) 83	(2) 80	(1) 0	(2) 83	(0) -
zinc	(22) 81	(3) 81	(1) 51	(4) 73	(1) 81

Source: Fate of Priority Pollutants in POTWS, EPA 440/1-82/303.

() Number of parenthesis is number of plants with one-week of analytical results included in data base.

2 Rotating Biological Contactor.

Land application of wastes has been performed and studied extensively for petroleum industry wastes. The efficiency of this treatment process has been well documented in terms of the biodegradability of organics and the optimum application rates for various soils. Less information is available, however, on the fate of trace metals and trace organics that may not be either adsorbed or biodegraded upon application (Canviro, 1982). Because this process involves many mechanisms and many possible fates for the contaminants, the overall treatment efficiency for all contaminants is difficult to assess. Studies which evaluate the biodegradation of petroleum wastes are summarized in Table 3-8.

TABLE 3-8

SUMMARY OF BIODEGRADATION RATES FOR PETROLEUM WASTES IN LAND TREATMENT

Material	Application Rate	Biodegredation Rate
crude oil	1.18% C in soil 4.26% C in soil 6.8 % C in soil	31% C removed (7 wks) 22% C removed (7 wks) 16% C removed (7 wks)
oily pretreatment sludge	20-25 lbs/ft^2	no sludge left after 6 months
crankcase oil	100 bb./ac.mo.	—
API refinery sludge	0.1-10 g C/100 g soil-180d	1/2 life = 141 days
API petrochemical sludge	0.1-10 g C/100 g soil-180d	1/2 life = 692 days
sludges	—	116 kg HC/ha./d.
sludges	—	25 g HC/20 g soil
sludges	100 ton HC/Ac	50% HC removed (2 yrs)
sludge	42 mg HC/g soil	48% HC removed

Source: P.A.C.E. 83-2

Biological treatment systems are capable of achieving very effective removal of hazardous wastes, principally of an organic nature although some processes effectively remove metals as well. These systems generally require acclimatization to a waste type, and may not achieve high treatment efficiencies for waste streams varying in concentration, flow or composition. Toxicity of contaminants to the microbial populations is also a concern. Many organic waste streams, however, are treated effectively by a suitably operated biological process.

Guideline 3-2: Batches of waste destined for physical-chemical-biological treatment should have a treatment recipe assigned to it in advance of arrival at the facility. Once an optimum treatment recipe has been developed for a generator's waste, the same recipe can be applied to successive batches of waste from the same generator. Additional treatability testing should only be required if the fingerprint analysis indicates a change in waste characteristics.

4.0 OPERATIONAL RISKS

4.1 Physical-Chemical Treatment Risks:

4.1.1 Environmental Risks

The physical-chemical treatment process usually introduces new chemical constituents into any effluent. If the nature and level of these contaminants is such as to exceed effluent regulations, additional measures are required to treat or dispose of the effluent.

Chemical Reduction

After chromium reduction for example, the treated solution should be acidic and should contain reduced chromium and other metals that were initially present in the waste stream. The solution requires neutralization prior to discharge in order to precipitate trivalent chromium and other metals that may be present.

Chemical reduction followed by neutralization and precipitation results in the formation of a sludge which requires disposal. These sludges may cause disposal problems because the metal hydroxides they contain are susceptible to acid leaching. A large portion of the sludge should consist of excess lime and calcium sulfate. Air emissions are of little significance from this process.

Oxidation

Alkaline chemical oxidation usually results in precipitation of metals as a sludge which requires disposal. An example is the sludge that develops in the oxidation treatment of cyanides when iron and other transition metal ions are present.

The only potential air emission is the possible production of HCN from the destruction of cyanide wastes if the reaction medium is allowed to become acidic. It is therefore essential that the reaction be kept alkaline and take place in a closed system with the vent gas treated for removal of any HCN that may be formed.

Neutralization and Precipitation

Many waste streams after neutralization have an increased total dissolved solids content owing to the addition of either Sulphuric Acid H_2SO_4 or Lime $Ca(OH)_2$.

Usually there is an accompanying reduction in the concentration of heavy metals if the treatment process proceeds to pH's greater than 8 (alkaline). In the neutralization of alkalies by acid, there is the possibility of solids dissolution. This may be a problem because when the suspended material is removed from the effluent, the cations and anions resulting from the neutralization, while not toxic nor hazardous, may not meet the recommended standards for discharge. The cation present after neutralization involving $Ca(OH)_2$ is calcium while the anions resulting from neutralization by H_2SO_4 is, of course, sulfate.

Inorganic heavy metal compounds are treated by reacting with hydroxides or in some cases, with sulfides to precipitate low solubility compounds that can be separated from the aqueous phase by flocculation and sedimentation.

One must be cautious when neutralizing wastes. Acidification of compounds containing sulfide produces hydrogen sulfide. In a closed system hydrogen sulfide is removed by the vent gas cleanup unit. The use of a closed reaction vessel is thus recommended for acid neutralization.

Precipitation, flocculation and sedimentation is basically a liquid- solid separation process resulting in two output streams; a high volume purified liquid stream, and a low volume sludge. Although air emissions from these processes are not of concern, equipment that exposes large open surfaces of liquid to the atmosphere is employed. While air emissions are seldom a problem for most applications, the exposed areas result in a potential for worker exposure.

The processes of precipitation, flocculation and sedimentation pose a minimal safety and health hazard. While chemicals such as alum and calcium hydroxide may be skin irritants, they are quite easily and routinely handled.

For further reducing the heavy metal content for some constituents, sulfide precipitation is used. Proper disposal of the sludge after sulfide precipitation is of concern, since long term exposure can result in oxidation of the sulfide to sulfate and re-solubilization of the metals.

Solidification/Stabilization

Solidification/stabilization is used to reduce the mobility of pollutants in the sludges prior to landfill. The waste must first be thoroughly characterized to determine the chemical compatibility with the solidification/stabilization process.

Stabilized wastes require disposal in landfills and the volume requiring disposal is usually increased by the process. The stability of these materials over long periods of time is not currently known. The wastes from the physical-chemical facility should meet the standard leachate test and compliance of the leachate test for each category of waste stream should have to be demonstrated.

Guideline 4-1: All waste storage, process reagent storage and treatment processes within the physical-chemical facility should be carried out in vessels which are totally enclosed and vented. Any vented gaseous emissions should be treated before they are discharged into the atmosphere.

Guideline 4-2: Storage tanks and reaction vessels should be under slight negative pressure. This should prevent fugitive gaseous emissions from escaping into the process buildings.

Guideline 4-3: Curbs around the base of each storage tank and reaction vessel should be provided to prevent migration of accidental spills or overflows. The curbs should be capable of containing the entire contents of the vessel.

4.1.2 Human Health Risks

Flammable and Explosive Material

Due to the nature of the inorganic materials being handled at the facility, risk to human health from flammable and explosive material is of minimal significance.

Corrosives

On the other hand, many of the treatment chemicals used are of a corrosive nature. Human health risks are controlled by exercising care when handling these chemicals. When working on equipment containing corrosive materials, goggles, as well as gloves of impermeable and resistant material are worn. A suit of impermeable and resistant material is also used in many instances.

Corrosion of equipment and piping may cause an undesirable release within the plant area and every effort should be taken to minimize corrosion attack within pipes and vessels.

Non-corrosive materials such as fibreglass or stainless steel, or protective non-reactive coatings should be selected in areas where high corrosion rates to normal materials of construction are anticipated.

Reactive

Reactive chemicals usually react relatively slowly compared to detonations and explosions. Usually a reaction can be controlled after the initiation, by cutting off the feed. Strong oxidizers such as chlorates, hypochlorites, perchlorates, permanganates, and peroxides are capable of uncontrolled reactions which can present severe risks to plant operators and caution in their treatment should be exercised.

Most of the wastes delivered to the plant should be in the aqueous phase. However, compounds that react with water may be also delivered to the site. These include sodium metal, aluminum alkalies, chlorosulfonic acid, phosphorous trichloride and calcium carbide, as well as concentrated mineral acids, including sulfuric, nitric acid and their mixtures. Any risks to human health would normally result from exposure to toxic or corrosive material generated by the reaction.

Toxic

Substances differ widely in their toxicity, their ability to enter the body, and the effects they produce. Toxicity is usually greatest by the route that carries the toxic substance to the bloodstream most rapidly. In decreasing order of speed, routes for most substances in the work place are:

- Inhalation to the respiratory system
- Mouth to gastrointestinal tract
- Skin contact absorption through the intact epidermis

There are three conditions that influence the toxicity of any given substance:

- Dose (Concentration x time)
- Rate of Absorption
- Route of Administration

Whether the toxic exposure comes from liquid, vapour, dust, or fumes (aerosol), the employee can be protected by a combination of personal protective equipment and engineering controls against chemical exposures. Providing respiratory protective devices should protect workers adequately from chemical hazards.

Facilities to permit worker hygiene must be provided at the facility. All employees must be required to adhere to high standards of bodily cleanliness. This justifies mandatory washing of the hands and face before smoking, drinking or eating. Mandatory daily showering and daily change to clean work clothes are required.

The Dangerous Properties of Chemicals encountered at a typical Physical Chemical Treatment facility are listed on Table 4.0-1.

Guideline 4-4: Emergency eye wash shower stations and respiratory equipment should be provided at strategic locations within the treatment facility.

Guideline 4-5: Care should be taken to ensure that contaminated materials are not inadvertently tracked from the active areas of the physical-chemical facility. Mandatory daily changes into clean work clothes is required.

TABLE 4-1

WASTE AND CHEMICAL CHARACTERISTIC RATING
FOR MATERIALS EITHER PROCESSED OR USED AT THE
PHYSICAL-CHEMICAL TREATMENT FACILITY

Chemical Compound	Toxicity	Persistence	Ignitability	Reactivity	Solubility	Volatility
Sodium Bisulfite (sol'n)	3	0	0	2	2	0
Sodium Hypochlorite (sol'n)	3	0	0	3	3	0
Sulfuric Acid	2 - 3	0	0	2	2	0
Calcium Hydroxide (sol'n)	1	0	0	1	2	0
Sodium Sulfhydrate (sol'n)	3	0	0	1	2	0
Flocculation Chemicals and Polyelectrolytes	1	0	0	0	1 - 2	0
Cadmium Plating Waste $Cd(CN)_2$	3	1	0	0	3	0
Chromium Plating Waste (Acid-Chromium)	3	1	0	0	3	0
Nickel Plating Wastes (Ni/Cu sulfates)	3	1	0	0	3	0

0 = none
1 = slight
2 = moderate
3 = severe or high

Ref: Sax - Dangerous Properties of Industrial Materials 5th Edition, and National Fire Protection Association's Guide on Hazardous Materials

4.2 Biological Treatment Risks:

4.2.1 Environmental Risks

The activated sludge process involves little environmental risks, because it employs natural microbial metabolic processes for waste treatment. The process is designed to encourage and enhance natural degradation. Gas emissions are carbon dioxide, water vapor and nitrogen. The liquid effluent contains some dissolved inorganics, and those soluble organics which have not been decomposed by microbial activity. The only significant emission is the biomass sludge. The sludge is a mixture of dead and living organisms, flocculated by their slimy cell coating, and containing non-biodegradable inorganics and refractory organics by their adsorptive capacity.

There are no chemicals added to the process except for sulfuric acid or calcium hydroxide injected into the feed to the equalization tank, if it is necessary to adjust the pH. The nutrients, coagulant aids and filter aids would present little or no environmental impact even if spills of these should occur. The three areas of contingency involving the greatest potential for environmental risk would appear to be:

- spills involving the incoming organic hazardous wastewaters.
- spills of sulfuric acid or calcium hydroxide solution.
- upset conditions in the activated sludge system resulting in poor BOD removal and/or excess carryover of suspended solids (unsettled microorganisms) in the effluent wastewater. This latter condition would normally be contained within the holding tanks.

There is potential for the sludge emissions to contain adsorbed metals and other inorganics, and refractory and non-biodegradable organics. To avoid this, and also to avoid the potential adverse affects on microbial metabolism caused by the presence of metals and non-biodegradable organics, the following rules must be adhered to:

- hazardous organic wastewaters containing metals and other inorganics must be subjected to physical-chemical treatment prior to biological treatment.
- since hazardous wastes containing non-biodegradable organics are obviously not treatable, alternate methods must be found for treatment. The physical-chemical-biological treatment facility may not be able to accept large quantities of wastes of this nature.
- refractory organics must be diluted with adequate quantities of readily biodegradable organics.

4.2.2 Human Health Risks

The human health risks involved in the activated sludge treatment of organic hazardous wastewaters include exposure to the hazardous wastewaters, and exposure to the chemicals used in the treatment; sulfuric acid, lime, flocculation chemicals and polyelectrolytes. As is indicated on Table 4.0-1, sulfuric acid exhibits severe or high toxicity while the toxicity of the other chemicals is slight. The toxicity of the hazardous organic compounds in the incoming wastewaters vary from minimal to high, however they should be present in dilute concentrations in the wastewaters.

The combination of protective equipment and clothing, as well as high standards of worker hygiene, as outlined in Section 4.1.2 for physical- chemical treatment, should also be applicable for biological treatment.

5.0 SITE SELECTION

Site selection for a physical-chemical-biological treatment facility for hazardous wastes is subject to all of the economic, environmental and social constraints that would be applicable to site selection for any project having significant potential environmental and socio-economic impact, such as chemical plants, refineries, fertilizer plants, etc. A very important addition to this, is the factor of public acceptance. It is essential that the siting of the treatment facility has the acceptance of the public and the community in which it is to be located.

A detailed discussion of site selection is not within the scope of this study, however, a brief discussion from the viewpoints of economic criteria, technical, environmental and social constraint criteria, and public acceptance criteria is as follows:

5.1 Economic Criteria:

These are the factors that impact primarily on the owner and/or operator of the treatment facility. They affect the capital costs and operating costs (including hazardous waste transportation costs), and hence the overall economic viability of the treatment facility. Some of the more important are as follows:

- proximity to waste generators
- proximity to adequate transportation facilities, including rail, highway, water and pipeline transport
- availability of a qualified and productive labour force
- availability of utilities such as electricity and natural gas or other fuels
- remoteness from populated areas. This should affect both capital and operating costs. A remote location can involve construction camp costs, and housing and/or transportation costs for permanent personnel.
- land costs
- site preparation costs; the extent to which clearing, earthmoving, rock excavation, etc. is required.

5.2 Constraint Criteria and Mapping:

These are the factors that must be considered to assure the technical viability of the treatment facility, and to minimize adverse environmental and socio-economic impacts on the community, as well as to maximize the potential economic benefits. They are based on four general considerations: physical, biological, land use and human environment. These criteria can be presented and evaluated using an overlay mapping technique or "constraint mapping." A more detailed discussion of the criteria is as follows:

5.2.1 Physical Factors

The effluent wastewaters from the physical-chemical-biological treatment facility may require disposal to a deep well or to surface waters. In such cases the site must be located above a suitable geological structure for deep well disposal, or near a stream or other waterbody of adequate assimilative capacity. Other physical constraints would be the avoidance of flood plain and/or wetlands locations.

The topography should be stable (not subject to landslides, slippage, etc.) and relatively level, and have suitable drainage and runoff characteristics to permit storm runoff diversion. The site should not be subject to weather extremes or climatic conditions which might inhibit adequate dispersion of air emissions.

5.2.2 Biological Factors

Not suitable as potential treatment facility sites would be areas exhibiting outstanding biological productivity, including forest productivity, wildlife, bird life, and aquatic productivity (fisheries). Also excluded are environmentally sensitive areas, such as critical migratory routes and staging areas, denning, birthing, nesting and spawning areas. Areas possessing rare, endangered or threatened species or habitats would also be excluded.

5.2.3 Land Use Factors

The physical-chemical-biological treatment facility must not be sited in areas where it conflicts with existing, planned and proposed land uses. Also excluded are locations which would use valuable agricultural land, or locations in national or provincial parks, or similar ecological reserves.

5.2.4 Human Environment Factors

The treatment facility must not be located where it will have an unacceptable social impact. This would include the negative impact of the facility, and the access routes to it, on residential populations, existing businesses, schools, hospitals, etc. resulting in noise and visual intrusion, reduced property values, displacement of residents and/ or businesses. It could also include such impacts as the downgrading or displacement of recreational facilities and other community features, historical and archaeological sites, etc.

The treatment facility would also have a positive impact on the regional and community economic base. This would result from additional employment and business opportunities, local benefits from facility taxes such as improved services and utilities upgrading, potential for industrial diversification, and improved local and regional waste management practices.

5.3 Public Acceptance Criteria:

To meet the requirement of public acceptance by the residents of the municipality, county, improvement district or other local jurisdiction, in which the physical-chemical-biological treatment facility is ultimately located, public participation must be an integral part of the site selection process from the outset. It should be a stage-wise process, consisting of the following general steps (based on the successful site selection process leading to the establishment of the Alberta Special Waste Treatment Centre at Swan Hills, Alberta):

- provincial government establishes public information programs to raise the public's awareness of the benefits of waste management. The information disseminated, outlines the program's policies and basic objectives (e.g. public safety and environmental quality), and indicates the manner in which the government intends

to have the waste treatment facility built and operated, and the proposed site selection process.

- preliminary "constraint mapping" of the province (or relevant regions) is carried out according to the criteria outlined in Section 5.2, and based on absolute criteria ("musts" and "must nots").
- information sessions (workshops) are held by the provincial government with representatives from each of the municipalities, counties, etc. identified by the preliminary constraint mapping to contain potentially suitable sites.
- further consideration of any community is by the "invitational process." The province carries out more detailed local constraint mapping only at the invitation of the individual municipalities. The more detailed assessment includes consideration of relative criteria, as well as absolute criteria.
- a short list of specific candidate sites is selected.
- detailed site specific studies (including deep drilling if applicable), conceptual designs, etc. are carried out for each candidate site.
- evaluation of the results of the studies is undertaken, and a site is selected.

Guideline 5-1: Site selection must address geotechnical, land use, biological socio-economic impact, human and environmental factors, past, present and potential future uses of the site.

Guideline 5-2: In the early stages of site selection, a mechanism such as constraint criteria mapping should be used as a screening process to warrant either exclusion or inclusion of a site. This process should be employed for detailed comparative evaluation amongst alternate sites.

Guideline 5-3: A staged approach for public participation should be carried out based on public awareness of why the facility is needed and recognition that public values and environmental quality will not be depreciated.

6.0 MONITORING

6.1 Process Monitoring:

6.1.1 Physical-Chemical Treatment

The process monitoring for physical-chemical treatment starts with the "fingerprinting" and/or complete chemical analysis that is performed on each drum or tank truck to accurately identify the waste to be treated. This forms the basis for the treatment recipe that is prepared for the operators by the plant technical personnel.

The principal process conditions that are monitored and controlled throughout the physical-chemical treatment steps are as follows:

Oxidation – level, temperature, pH, ORP, time
Reduction – level, temperature, pH, ORP, time
Neutralization and Precipitation – level, temperature, pH, time
Gravity Separation – sludge level, setting rate, flocculent addition
– complete analysis of all relevant effluent criteria on effluent water holding tanks
Pressure Filtration – pressure drop
Solidification/Stabilization – leachate extraction test
Vent Gas Cleanup – acid and alkali solution analysis

6.1.2 Biological Treatment

The major monitoring concerns in the activated sludge biological treatment process relate to the provision of a proper environment for the microorganisms. The system must be adequately monitored to avoid shock loadings in the aeration basin, and ensure good liquids-solids separation in the clarifier. The key control point is the equalization tank. Here the pH levels, BOD levels, refractory organics levels and flow rates must be maintained by means of tight inventory control on influent wastewater feeds.

Dissolved oxygen content and nutrient levels in the aeration tank should be checked and maintained. The need for clarified flocculent addition must be assessed and controlled. A complete analysis of all relevant effluent criteria must be performed on composite samples of the treated water entering the effluent holding tanks. Dissolved air flotation operation requires maintenance of the proper air to solids ratio, and flocculent addition rate. Filter press cycles are based on monitoring the pressure drop.

6.2 Environmental Monitoring:

The requirements for environmental monitoring of water vary, depending on whether the treatment facility is discharging its effluent water to the watershed, into a municipal sewage system or down a deep well. Storm runoff in the plant area is also impounded and tested prior to discharge to watershed. On this basis, environmental monitoring of ambient water might be adequate if done on a seasonal frequency.

The same approach is applicable to air emissions, since dispersion is not relied upon to meet ground level criteria, in the manner in which this applies, for example, to sulfur dioxide emissions.

6.3 Source Monitoring:

This applies to monitoring at the source of all water and air discharges from the physical-chemical-biological treatment facility. As described above, the design and operation of the typical facility are based on holding tanks for water effluent streams from both physical-chemical and biological treatment processes, to permit full analyses of effluent water before release. Frequency of analysis would depend on the size of the holding tanks, but typically would be in the order of 12 to 24 hours for the batch physical-chemical treatment, and 8 to 10 hours for the continuous biological treatment. Composite samples would be taken of the water entering the biological holding tanks. Grab samples would be taken from the phys/chem holding tanks. Additional grab samples would be taken on both water streams entering the holding tanks for process control purposes.

Grab air samples should be taken daily on the discharge of the vent gas cleanup unit, and the particulate removal bag filters on the fly ash and lime storage day tanks.

Analytical methods for both water and air samples may be such as outlined in:

- "Standard Method for the Examination of Water and Waste Waters," 16th Edition APHA, AWWA, WPCF (1985)
- "Method Manual for Chemical Analysis of Atmospheric Pollutants," Alberta Environment

or other reputable test manuals.

The quality control laboratory located at the physical-chemical-biological treatment facility is required to perform sophisticated analyses, particularly when identifying unknown hazardous waste receipts. For this reason a quality assurance program, probably supplied by an outside contract laboratory, should be required. Quality control is defined as the internal operations performed during an analysis to document the quality of the data. Quality assurance refers to the operations, performed on an occasional basis by an independent person, to assess the overall quality of the analyses, including the quality control system.

Health monitoring is another important requirement for the personnel of a physical-chemical-biological treatment facility for hazardous wastes. A thorough pre-employment medical examination is necessary. Regular medical examinations should be conducted every six to twelve months, with special emphasis on early detection of any condition that might be attributed to over-exposure to any of the substances handled.

Guideline 6-1: Sample analysis and treatability test information should be used to establish treatment recipes for wastes prior to physical- chemical-biological treatment.

Guideline 6-2: Quality control checks should be carried out during the treatment sequence to ensure that treatment is proceeding as planned.

Guideline 6-3: Quality control checks should be carried out after treatment to confirm that the treated effluent meets the required standard.

Guideline 6-4: All personnel at the physical-chemical-biological facility should be subjected to both pre-employment and regular medical examinations.

Guideline 6-5: In addition to the regular source monitoring program, a quality assurance program should be initiated, preferably by an outside laboratory.

7.0 EFFLUENT CRITERIA

The performance of the physical-chemical-biological treatment system can only be judged by assessing the capability of the system for removing specific chemical contaminants which are expected to be present in the untreated wastes. Due to the nature of the physical-chemical-biological process it is not possible to generalize about the removal efficiency of all contaminants together. The level of treatment attainable for each contaminant in a complex waste mixture depends uniquely upon a number of interrelating factors.

Final effluent concentrations are generally easier to predict for **inorganic** contaminants than for organics because more treatability data is available on inorganics. Also, removal efficiencies of inorganics are less affected by influent concentrations. Data from European physical- chemical facilities are of assistance in establishing levels of attainability for inorganic contaminants.

The concentration of **organic** contaminants in the treated effluent from a physical-chemical-biological facility is more difficult to predict. Existing European hazardous waste treatment facilities do not measure specific organic contaminants in their treated effluents. It is not possible, therefore, to verify the data that is available in the literature. A number of features have been incorporated into the design philosophy of the treatment facility to ensure that the plant performs in a manner which ensures acceptable levels of risk to human health and the environment.

7.1 Liquid Effluent Discharge:

Several factors influence the establishment of liquid effluent discharge levels including:

- Potential adverse environmental impacts on the receiving body of water, on aquatic organisms and on users of the water.
- Site specific information such as presence or absence of other waste dischargers in the area, evaporation rates, the assimilative capacity or the receiving waters and the processes to be used.
- The technical and the economic feasibility of reducing contaminants to the required levels.

Most of these factors must be accounted for on an individual site specific basis. The lowest level of attainability of effluent concentrations may be used as a yard stick against which the expected performance of physical-chemical-biological treatment facilities can be gauged.

7.1.1 Inorganic Contaminants

In the case of inorganic contaminants, most notably metals, a variety of technologies have been employed to "polish" the final waste treatment effluent for discharge.

Precipitation, sedimentation, coagulation and filtration are often the preferred choices in the treatment stage of inorganic wastes. Metals are precipitated as hydroxides or sulfides and removed as sludge for subsequent treatment and disposal. The degree to which a metal precipitates out of a solution is largely a function of pH. Figure 7-1 illustrates the soluble metal concentrations theoretically attainable as a function of pH. All the optimum concentration may be used as an estimate of the level of attainability achievable by precipitation and sedimentation. A final

neutralization stage may be required prior to discharge to adjust the pH from the optimum for low metal solubility to the range required for effluents.

Case studies of treatment facilities and laboratory investigations of the optimization of metals removal from waste waters are frequently reported in the literature. Table 7-1 summarizes the lowest effluent concentration of metals and cyanide from various polishing treatment processing, as reported in several extensive technology reviews. While these effluent concentrations were developed from varying conditions and for specific waste streams, they are representative of levels of attainability for effluent discharge. Site specific situations should also be taken into account.

One obstacle frequently encountered in evaluating the levels of attainability in effluents is the detection limits of the analytical procedures used. Many reports of treatment processes claim effluent with contaminant levels below detection limits, without stating what these detection limits are. In cases where the lowest possible effluent concentration is desired, the lower levels of detection may be considered as discharge guidelines. Table 7-2 lists the detection limits for metals.

7.1.2 Organic Contaminants

One of the most commonly used polishing treatment processes involving organic contaminants is activated carbon adsorption. Applicable to a wide variety of organic wastes, carbon adsorption can potentially result in very low effluent concentrations and may be assumed to represent one of the best available technologies for organics removal. Table 7-3 summarizes the effluent concentrations of a number of organic contaminants that may be achieved by activated carbon adsorption. Again, these levels or attainability should be used as guidelines for organic contaminants of the most concern, environmentally and in situations where very sensitive areas serve as the receiving waters.

The determination of attainable effluent criteria for organic contaminants is an exceedingly difficult task. Detection limits of organic contaminants vary considerably due to such factors as sample size, sample matrix, sample type, and analytical procedures. Generally, because of the vast number of organic compounds, it is difficult to establish effluent criteria for all wastes and all compounds. Appendix D summarizes levels of attainability for many organics and may be used as a rough guideline. Shuckrow et al (1981) provides similar information. While these sources and Table 7-3 should be used as a reference in the establishment of effluent concentrations, additional factors should be considered once the individual characteristics of the waste stream is known.

7.1.3 Existing Liquid Effluent Criteria

Table 7-4 summarizes objectives of established effluent quality in various jurisdictions for hazardous waste treatment facilities. These criteria are presented here as a comparative reference of the standards that have been enacted. The U.S. EPA has established effluent limitations for the organic chemical industry based on Best Available Technology requirements (BAT) and New Source Performance Standards, in the form of maximum daily effluent limitations and maximum average monthly limitations. These standards are presented in Table 7-5.

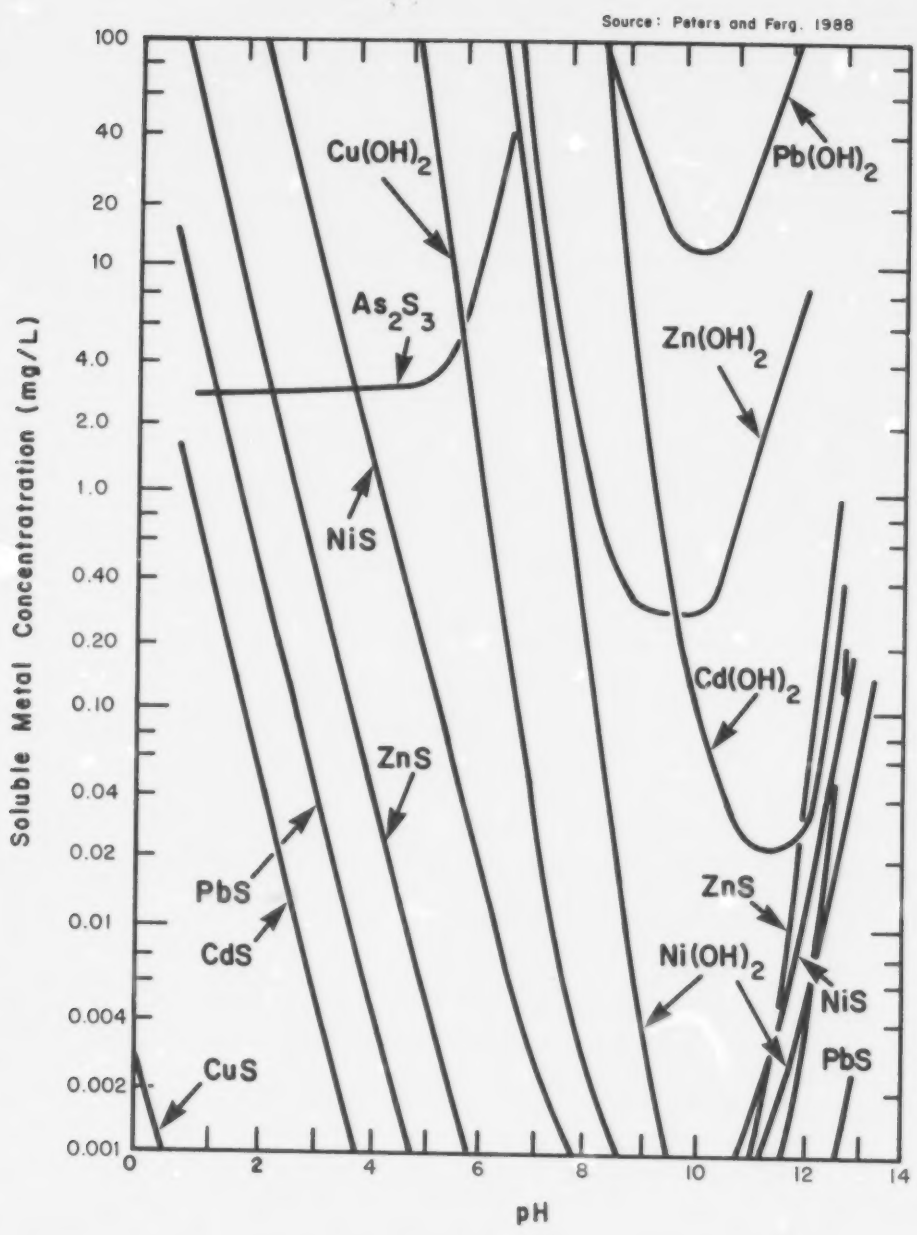


Figure 7-1 Solubilities of Metal Hydroxides and Metal Sulfides as a Function of pH.

TABLE 7-1

LOWEST REPORTED EFFLUENT CONCENTRATIONS FOR METALS AND CYANIDE FROM WASTE TREATMENT PROCESSES

Pollutant	Treatment Process	Possible Low-End Concentration (mg/l)*	Ref.
Antimony	Precipitation/Coagulation	0.21	1
Arsenic	Coagulation, + Sediment. & Filt.	0.05	5
Barium	Precipitation, & Filtration	1	5
Beryllium	Precipitation/Coagulation	0.001	1
Cadmium	Precip., + Filt. & Activ. Carbon	0.002	5
Chromium	Activated Carbon	0.006	3
Copper	Precipitation/Sedimentation	0.0001	4
Iron	Reverse Osmosis	0	1
Lead	Precipitation	0.001	7
Manganese	Precipitation/Sedimentation	0.05	5
Mercury	Precipitation/Sedimentation	0.0001	4
Nickel	Precipitation, & Filtration	0.1	5
Selenium	Precip., + Filt. & Activ. Carbon	0.002	5
Silver	Precipitation/Coagulation	0.0037	1
Thallium	Precipitation/Coagulation	0.2	1
Zinc	Precipitation, & Filtration	0.1	5
Cyanides	Chlorine Oxidation	0	3

* Lowest effluent concentration reported in the literature, excluding reports of concentrations below detection limits. Note that final effluent concentrations are dependent on influent concentrations, and other factors as discussed in the text.

References:

1) Shuckrow et al, 1981
2) Martin and Johnson, 1987
3) U.S. EPA, 1986
4) Monenco, 1986
5) Lin and Lawson, 1973
6) U.S. EPA, 1982
7) Eckenfelder et al, 1985

TABLE 7-2

TYPICAL TRACE METAL DETECTION LIMITS

ATOMIC ABSORPTION CONCENTRATION RANGES ATTAINABLE WITH CONVENTIONAL ATOMIZATION * (AQUEOUS SAMPLES)**

Metal	Detection Limit (mg/l)	Sensitivity (mg/l)	Optimum Concentration Range (mg/l)	Detection Limits for Effluents (mg/l)
Aluminum	0.1	1	5 – 100	0.15
Antimony	0.2	0.5	1 – 40	0.003
Arsenic*	0.002	-	0.002 – 0.02	0.001
Barium	0.03	0.4	1 – 20	0.005
Beryllium	0.005	0.025	0.05 – 2	0.003
Cadmium	0.002	0.025	0.05 – 2	0.001
Calcium	0.003	0.08	0.2 – 20	0.10
Chromium	0.02	0.1	0.2 – 10	0.001
Cobalt	0.03	0.2	0.5 – 10	0.02
Copper	0.01	0.1	0.2 – 10	0.001
Iron	0.02	0.12	0.3 – 10	0.010
Lead	0.05	0.5	1 – 20	0.001
Magnesium	0.0005	0.007	0.02 – 2	0.01
Manganese	0.01	0.05	0.1 – 10	0.003
Mercury**	0.0002	-	0.0002 – 0.01	0.0002
Molybdenum	0.1	0.3	0.5 – 20	0.04
Nickel	0.02	0.15	0.3 – 10	0.005
Potassium	0.005	0.04	0.1 – 2	0.50
Selenium*	0.002	-	0.002 – 0.02	0.001
Silver	0.01	0.06	0.1 – 4	0.001
Sodium	0.002	0.015	0.03 – 1	0.50
Thallium	0.1	0.5	1 – 20	0.001
Tin	0.8	4	10 – 200	-
Titanium	0.3	2	5 – 100	0.006
Vanadium	0.2	0.8	1 – 100	0.01
Zinc	0.005	0.02	0.05 – 2	0.001

* Gaseous hydride method

** Cold Vapour technique

*** the concentrations shown above are not contrived values and should be obtainable with conventional aspiration on any satisfactory atomic absorption spectrophotometer or ICP spectrograph.

Source: P.A.C.E. Report No. 83-2

TABLE 7-3

ATTAINABLE CONCENTRATIONS OF ORGANIC CONTAMINANTS FOLLOWING ACTIVATED CARBON ADSORPTION

Organic Compounds	Influent Concentration Range	Carbon Effluent Concentration Achieved
Carbon tetrachloride	130 ug/l-10 mg/l	<1 ug/l
Chloroform	20 ug/l-3.4 mg/l	<1 ug/l
DDD	1 ug/l	<.05 ug/l
DDE	1 ug/l	<0.05 ug/l
DDT	4 ug/l	<0.05 ug/l
CIS-1,2-dichloroethylene	5 ug/l-4 mg/l	<1 ug/l
Dichloropentadiene	450 ug/l	<10 ug/l
Disopropyl ether	20-34 ug/l	<1 ug/l
Tertiary methyl-butylether	33 ug/l	<5.0 ug/l
Diisopropyl methyl phosphonate	1,250 ug/l	<50 ug/l
1,3-dichloropropene	10 ug/l	<1 ug/l
Dichlorethyl ether	1.1 mg/l	<1 ug/l
Dichloroisopropylether	0.8 mg/l	<1 ug/l
Benzene	0.4-11 mg/l	<1 ug/l
Acetone	10-100 mg/l	<10 mg/l
Ethyl acrylate	200 mg/l	<1 mg/l
Trichlorotrifloroethane	6 mg/l	<10 ug/l
Methylene chloride	1-21 mg/l	<100 ug/l
Phenol	63 mg/l	<1 ug/l
Orthochlorophenol	100 mg/l	<1 mg/l
Tetrachloroethylene	5 ug/l-70 mg/l	<1 mg/l
Trichlorethylene	5 ug-16 mg/l	<1 ug/1
1,1,1-trichloroethane	60 ug/l-25 mg/l	<1 ug/l
Vinylidiene chloride	5 ug/l-4 mg/l	<1 ug/l
Toluene	5-7 mg/l	<10 ug/l
Xylene	0.2-10 mg/l	<101 ug/l

Source: O'Brien & Fisher, 1983, as cited in U.S. EPA 1985

Tables 7-6 and 7-7 indicate the recommended levels of attainability for the physical-chemical-biological facility. The Physical and Inorganic parameters in Table 7-6 are presented on the basis of Best Practicable Technology commonly accepted effluent criteria and experience elsewhere. The selected organic parameters are based on best available technology and should be used as a **guide** for organic contaminants in physical- chemical-biological facility effluents. For all parameters; physical, inorganic and organic, the levels presented are on the basis of current knowledge and these levels may have to be revised as more is learned about the treatability and the environmental effects of these contaminants.

Guideline 7-1: Dilution or blending of hazardous waste residues or effluents should not be allowed for the sole purpose of achieving permitted concentration limits.

Guideline 7-2: Effluent attainability criteria is available for a number of inorganic and organic parameters of concern. It is important to emphasize that there is considerable variability in these data depending upon the treatment application, waste types and influent contaminant concentrations. The recommended effluent parameters in Tables 7-6 and 7-7 should provide sufficient environmental protection. Due to the vast number of *organic* compounds, it is difficult to establish effluent criteria for all wastes and all compounds. Appendix D summarizes levels of attainability for many organics and may be used along with Tables 7-3 and 7-5 as a rough guideline for specific organics once the individual characteristics of the waste stream are known.

TABLE 7-4

EFFLUENT CRITERIA FOR HAZARDOUS WASTE TREATMENT FACILITIES

	Ontario MOE Objectives mg/l	B.C. Special Waste Legislation mg/l	Frankfurt W. Germany mg/l
Oil and Grease	15.0	10.0	20.0
Phenol	0.02	0.2	-
Cyanide	0.1	0.1	0.2
Arsenic	1.0	0.1	0.1
Lead	1.0	0.1	2.0
Cadmium	0.001	0.01	0.5
Iron	1.0	Not Specified	20.0
Copper	1.0	0.1	2.0
Nickel	1.0	0.2	3.0
Mercury	0.001	0.001	0.05
Selenium	Not Specified	0.05	1.0
Silver	Not Specified	Not Specified	2.0
Zinc	1.0	0.2	5.0

Source: Ontario MOE Objectives
B.C. Special Waste Legislation

TABLE 7-5

BAT EFFLUENT LIMITATIONS AND NSPS FOR THE NON-END-OF-PIPE BIOLOGICAL TREATMENT SUBCATEGORY

Pollutant Number	Pollutant Name	BAT EFFLUENT LIMITATIONS AND NSPS[1] Maximum for Any One Day ug/l	Maximum for Monthly Average ug/l
1	Acenaphthene	47	19
3	Acrylonitrile	232	94
4	Benzene	134	57
6	Carbon Tetrachloride	380	142
7	Chlorobenzene	380	142
8	1,2,4-Trichlorobenzene	794	196
9	Hexachlorobenzene	794	196
10	1,2-Dichloroethane	574	180
11	1,1,1-Thrichloroethane	59	22
12	Hexachloroethane	794	196
13	1-1-Dichloroethane	59	22
14	1,1,2-Trichloroethane	127	32
16	Chloroethane	295	110
23	Chloroform	325	111
25	1,2-Dichlorobenzene	794	196
26	1,3-Dichlorobenzene	380	142
27	1,4-Dichlorobenzene	380	142
29	1,1-Dichloroethylene	60	22
30	1,2-Trans-dichloroethylene	66	25
32	1,2-Dichloropropane	794	196
33	1,3-Dichloropropene	794	196
34	2,4-Dimethylphenol	47	19
38	Ethylbenzene	380	142
39	Fluoranthene	54	22
42	Bis(2-Chloroisopropyl)ether	794	196
44	Methylene Chloride	170	36
45	Methyl Chloride	295	110
52	Hexachlorobutadiene	380	142
55	Naphthalene	47	19
56	Nitrobenzene	6,402	2,237
57	2-Nitrophenol	231	65
58	4-Nitrophenol	576	162
59	2,4-Dinitrophenol	4,291	1,207
60	4,6-Dinitro-o-cresol	277	78
65	Phenol	47	19
66	Bis(2-ethylhexyl)phthalate	258	95
68	Di-n-butyl phthalate	43	20
70	Diethyl phthalate	113	46

SOURCE: U.S. EPA Standards for Organic Chemical Industry

TABLE 7-5 (continued)

BAT EFFLUENT LIMITATIONS AND NSPS FOR THE NON-END-OF-PIPE BIOLOGICAL TREATMENT SUBCATEGORY

Pollutant Number	Pollutant Name	BAT EFFLUENT LIMITATIONS AND NSPS[1] Maximum for Any One Day ug/l	Maximum for Monthly Average ug/l
71	Dimethyl phthalate	47	19
72	Benzo(a)anthracene	47	19
73	Benzo(a)pyrene	48	20
74	3,4-Benzofluoranthene	48	20
75	Benzo(k)fluuoranthene	47	19
76	Chrysene	47	19
77	Acenaphthylene	47	19
78	Anthracene	47	19
80	Fluorene	47	19
81	Phenanthrene	47	19
84	Pyrene	48	20
85	Tetrachloroethylene	164	52
86	Toluene	74	28
87	Trichloroethylene	69	26
88	Vinyl Chloride	172	97
119	Total Chromium[2]	2,770	1,110
120	Total Copper[2]	3,380	1,450
121	Total Cyanide[3]	1,200	420
122	Total Lead[2]	690	320
124	Total Nickel[2]	3,980	1,690
128	Total Zinc[2]	2,610	1,050

1 All units are micrograms per liter.

2 Metals limitations apply only to noncomplexed metal-bearing waste streams. Discharges of chromium, copper, lead, nickel, and zinc from "complexed metal-bearing process wastewater," are not subject to these limitations.

3 Cyanide limitations apply only to cyanide-bearing waste streams.

SOURCE: U.S. EPA Standards for Organic Chemical Industry.

TABLE 7-6

RECOMMENDED EFFLUENT CRITERIA FOR PHYSICAL-CHEMICAL-BIOLOGICAL PLANT

(Inorganics and Physical Parameters)

Parameter	Maximum Concentration or Range in (mg/l) unless otherwise specified
Physical	
pH	6.5 to 8.5
Temperature	32°C
Suspended Solids	15
Toxicity Limit (bioassay)	100% effluent
Inorganics	
Aluminum, dissolved	0.1
Ammonia, dissolved (as N)	1.0
Antimony, dissolved	0.25
Arsenic, dissolved	0.1
Barium, dissolved	1.0
Boron, dissolved	10.0
Cadmium, dissolved	0.1
Chromium, dissolved (hexavalent)	0.1
Chromium, total	0.5
Cobalt, dissolved	0.1
Copper, dissolved	0.1
Cyanide (as HCN)	0.1
Fluoride, dissolved	15.0
Lead, dissolved	0.1
Manganese, dissolved	0.5
Mercury, total	0.001
Molybdenum, dissolved	0.5
Nickel, dissolved	0.5
Selenium, dissolved	0.05
Tin, dissolved	0.5
Zinc, dissolved	0.2

Source: B.C. Ministry of Environment and Parks, "Special Waste Regulation," March 1988

TABLE 7-7

RECOMMENDED EFFLUENT CRITERIA FOR PHYSICAL-CHEMICAL-BIOLOGICAL PLANT

(Selected Organics)

Parameter	Maximum Concentration or Range in (mg/l) unless otherwise specified
Organics	
5 day Biochemical Oxygen Demand	20
Oil	10
Phenol	0.02
Polychlorinated biphenyls, total	0.005
Polychlorinated dibenzo furans, total	30 ng/l
Polychlorinated dibenzo-p-dioxins, total	30 ng/l
Total organic halogens	0.5
Aldrin	6×10^{-5}
Lindane	6×10^{-6}
Methylene Chloride	0.5
Carbon Tetra Chloride	0.013
Trichloroethyene	0.025
Chloroform	0.006
Bis (2-Chloroethyl) ether	0.1
Benzene	0.015
Hexachlorobenzene	5×10^{-4}
Acenaphthene	0.012
Benzo (k) Fluroanthene	0.001
Butyl-Benzyl-Phthalate	6×10^{-4}
Acrylonitrite	0.20
2, 4, 6-Trichlorophenol	0.002
2-Chlorophenol	0.002

Source: Shuckrow et al, 1981

U.S. EPA, "Hazardous Waste Treatment Technology," EPA/600/D-86/006, 1986

7.2 Solid Waste Disposal:

Solid waste requiring disposal from physical-chemical treatment facilities include inorganic sludges and residues from the various processes, as well as some organic sludges from the biological processes such as activated sludge and activated carbon. There are two potential disposal options for this waste:

- **incineration** — suitable for organic sludges, activated carbon and solids, resulting in an ash which would require landfill disposal.
- **landfill disposal** — suitable for inorganic and some organic sludges and residues which meet acceptance criteria such as slump tests and paint filter tests, or which may be stabilized or solidified as described in Section 2.1.7.

Much work has already been done to establish operating requirements and emission criteria for hazardous waste incinerators and is beyond the scope of this study. In landfill disposal, due to the uncertainty of long term performance of stabilization and solidification techniques, physical-chemical-biological facility residues should be disposed on in secure landfills. A considerable amount of work has been done on the establishment of design and operating criteria for such landfills (Reid Crowther, 1988) and will not be discussed here.

7.3 Air Emissions:

Gases produced in physical-chemical-biological treatment processes under proper operating conditions should primarily consist of non-pollutants such as carbon dioxide and nitrogen. Under upset conditions, however, or with some unknown or volatile organics entering into the treatment process, toxic gases may invariably be produced. The unloading, transferring and storage of wastes may also result in fugitive emissions. Effort should be taken to minimize and eliminate these emissions to the maximum extent possible.

Guideline 7-3: The following measures should be incorporated into the design of treatment facilities wherever possible:

- **Direct unloading of waste from tanker trucks to storage tanks by way of sealed interconnected piping to avoid any emission of vapours.**
- **Vent systems installed on all receiving tanks, storage tanks and blending or mixing vessels to capture any vapours that may be generated. Contaminant removal systems such as activated carbon units or scrubbers should be installed to clean the vent air prior to release. Alternatively, the vent air could be discharged to an incinerator, if available.**
- **Treatment of wastes should be carried out in enclosed vessels with vent systems or contaminant removal systems.**
- **Minimization of waste and reagent transfers, with treatment, performed as close to reagents and to ultimate disposal.**
- **Containment or minimization of particulate emissions arising from the solidification/stabilization process and landfill disposal. Solids should be transferred in slurries where possible to eliminate dust emissions.**
- **Particular attention should be exercised in areas where operator error could result in conditions that cause the production of toxic emissions.**

These areas should be enclosed and equipped with vent gas treatment equipment.

- **Good housekeeping and maintenance should be practiced to avoid leaks, spillage and to ensure proper operation of vent systems.**

7.4 Zero Discharge:

Typical physical-chemical technologies concentrate the more hazardous portion of the waste into a smaller volume for treatment and disposal. The amount of effluent therefore depends upon the waste and the concentration of contaminants. In biological systems the total discharge is approximately equal to the incoming stream.

The options for zero surface water discharge include use of the treated effluents for the stabilization/solidification process, deep well injection, or evaporation.

Zero surface discharge by solidification is the least complex of the alternatives. It eliminates discharge to surface waters by solidifying all of the liquid effluents. Few technologies are required; neither dewatering nor precipitation are needed since both the sludge and liquid streams generated are completely solidified. Land requirements are high as well as operating costs due to the large volume of liquid requiring disposal.

Deep well injection is a process used for many years in the oil industry for disposal of brine or formation water associated with oil. It is a convenient method of disposal of liquid effluents providing a suitable deep formation can be located for injection.

Evaporation is a process for concentrating solution or slurries by the addition of heat to vapourize a portion of the liquid. Evaporation is usually carried out in equipment designed specifically for this purpose such as multi-effect, vapour compression, multi-flash systems or evaporative driers. After evaporation the effluent may be stabilized and landfilled.

8.0 CONTINGENCY PLANNING

8.1 Fire Protection:

Although the amount of flammable material being received by the plant should be negligible, the threat of fire to both process equipment and offices should be considered. Fire protection can be divided into two categories:

1) minimize the chance of a fire occurring,
2) containment of the fire once it has begun.

The plant must have a well defined scene management structure in case of a fire; it should also have a good communications system, trained personnel, vehicles and equipment designed for handling specific situations, mutual assistance with the local communities, working relationships with the local fire department, law enforcement agencies, and the media, and other identified resources from the public and private sector. Training activities should include plant personnel as well as the local community fire department personnel. The level of both can be improved and deficiencies may be improved.

There are a number of valuable functions that plant personnel should perform if a fire department is located nearby to increase the awareness of the local fire service personnel to better handle a hazardous material emergency. The plant should support any local fire department with the necessary additional resources and offer to provide a response team with specialized equipment.

The plant should have waste product information available. In many cases a local fire department's technical knowledge and experience in handling a specific waste or chemical may be limited. Plant personnel should be incorporated into the response structure both on-site and off-site to provide a well-rounded hazardous material incident emergency response team.

Generally, the role of the local fire department at hazardous materials incidents is to rescue endangered people, isolate the site, or control the released materials and stabilize the situation. Plant officials must arrange for recovery and clean-up where necessary.

8.2 Spill Response:

Based on experience in California approximately one spill occurs for every 10 million gallons delivered to the facility. Any impact of an on-site spill would depend upon such factors such as the specific hazard of the substance involved, the amount spilled, the nature of the incident, and weather conditions, e.g. if the spill occurs outdoors. Spilled contaminants may volatilize or be absorbed rapidly by the soil. Volatilization of liquids or an associated fire may result in subsequent release of contaminants to the air. Normally quantities spilled are quite small, however, depending upon the material, a spill at a hazardous waste facility may pose a risk to human health and environment. Operating personnel must be trained to deal with incidents such as these by thorough drills and practice. Each of the operating crew must have clearly designated tasks and must automatically perform these tasks so that if a spill occurs, it is acted upon quickly and as effectively as possible. The operating crews must also be thoroughly familiar with each other's responsibilities during a spill response.

The most important thing to consider with a liquid spill is containment. The isolation of a hazard area should begin immediately. Isolation could involve halting of all movement through the hazard area. All forms of traffic should be considered depending upon the magnitude of the spill and the subsequent effects.

It is important to know just what is a **Dangerous Occurrence** as defined under the **Transport of Dangerous Goods Regulations**. For each class there is a quantity limit above which any "discharge, emission or escape" must be reported. Spills within the facility may be reportable if they meet the severity criteria of a danger to health, life or property. Spills over the following limits are included in this category of **Dangerous Occurrence**:

Class 1	Explosives	All
Class 2.1/2.2	Gases	Any amount from containers
Class 2.3/2.4	Gases	All
Class 3	Flammable liquids	200 litres or over
Class 4	Flammable solids	25 kg or over
Class 5.1	Oxidizers	50 kg/50 litres or over
Class 5.2	Organic Peroxides	1 kg/1 litre or over
Class 6.1	Poisons	5 kg/5 litres or over
Class 6.2	Infectious	All
Class 8	Corrosive	5 kg/5 litres or over
Class 9.1	Miscellaneous	50 kg or over
Class 9.2	Environmental	1 kg or over
Class 9.3	Dangerous Waste	5 kg/5 litres or over

An ample supply of absorbent materials, empty drums, shovels, picks and squeegees should be readily available on site. Spill clean-up is facilitated if all working or active areas of the plant site are paved and bermed so that the spill cannot penetrate or migrate into the soil subsurface.

Correct identification of the hazardous material spilled is critical to any response. Plant operators should regularly train and provide their personnel with the equipment and protection to handle small spills. Knowing what is spilled, what to do, and having the right equipment is critical to spill management. If the spill is very large, is unmanageable by the shift crew, or there is a major incident that includes a fire, then assistance from local fire, police or emergency measures personnel may be necessary.

Hazardous materials may become airborne, and spread by wind and other natural forces, and every effort should be made to prevent contamination to occur outside the immediate spill area.

Decontamination of protective clothing, of transport vehicles, and of other material should be carried out immediately at the site of the incident. It may be difficult to keep contamination within a prescribed area. Contamination may be inadvertently spread, thus increasing the potential area for which cleanup may have to be carried out.

The prevention of a catastrophic event through proper spill management, facility design, inspection, maintenance, leak detection, and an inhouse rapid response is essential. A catastrophic event is exceedingly rare, however, thorough preparation, when combined with a very

early warning to the population centres at risk and to the public safety and emergency response teams, should allow appropriate action or rapid organization of medical response.

This should provide more benefit than trying to organize and make preparations that would respond to a hazardous materials disaster after it occurs.

In general, a well-operated and well-designed physical-chemical-biological facility should pose no more of a hazard than a small chemical facility or industrial facility of a similar nature. Because of the increased awareness and increased concern over safety, the potential for any hazard to both health and environmental degradation should be considerably reduced.

Guideline 8-1: A comprehensive contingency plan should be prepared for the physical-chemical-biological facility. It should be distributed and reviewed by all staff, and should include any realistically foreseeable mishaps which may occur at the physical-chemical-biological facility. The plan should be prepared in consultation with provincial and local emergency response authorities.

Guideline 8-2: The contingency plan for the facility should be reviewed and amended on a regular basis to reflect changes in personnel, response procedures, technology or response equipment.

Guideline 8-3: All physical-chemical-biological plant personnel should be given regular comprehensive training programs. These training programs should include local community emergency response personnel.

9.0 DECOMMISSIONING

When the physical-chemical-biological treatment facility has come to the end of its useful life, it must be removed and the site restored, insofar as possible, to its original condition or in keeping with the intended land use. Planning for decommissioning of the facility should be undertaken during the initial planning stages of the overall project. By integrating decommissioning requirements into the facility design at the outset, the site development plan should be compatible with the proper closure requirements when the operation of the facility has ended. This should take place in three stages: cleaning and decontamination, dismantling and demolition, and site restoration. These are described briefly as follows:

9.1 Cleaning and Decontamination:

When the final inventories of hazardous wastes have been processed, and equipment has been emptied, it will be necessary to clean and decontaminate all vessels, tanks, piping, pumps, heat exchangers, filters, solids and sludges handling equipment, etc. that have been used to process hazardous wastes, handle treatment chemicals or cleanup vent gases. For the most part, water rinsing and flushing can be used, the spent wash waters being contained and sent to another hazardous waste treatment facility for processing.

Chemical cleaning will also be necessary to remove more resistant buildups and deposits. The chemical cleaning agents used in industrial cleaning are primarily for the solvent cleaning of heat exchange equipment, and to a lesser extent vessels and piping. The work is generally carried out by chemical cleaning contractors, using specially built tank trucks equipped with pumps and heaters to circulate hot solutions through the equipment being cleaned, and back to the tank truck. The cleaning agents are generally aqueous solutions of strong or weak acids, to which are added suitable corrosion inhibitors and other additives as required, such as surfactant/detergents, dispersants, etc.

The cleaning contractor should have laboratory facilities where samples of the deposits to be removed can be tested to determine the most effective cleaning formula, prior to commencing the work.

The cleaning process is generally carried out in two basic steps: acidizing and passivating. The latter step involves circulation of an alkaline solution through the equipment to neutralize the acid and passivate the metal surface, which has been left in an active state by the acidizing process. Water rinses are conducted after acidizing or after passivating, or after both. The spent acid and passivating solutions and the rinse waters must be contained and transported to another hazardous waste treatment facility for processing.

9.2 Dismantling and Demolition:

After cleaning and decontamination is completed, the equipment, piping, electrical, instrumentation can be dismantled, and disposed of as used equipment or scrap metal. Materials of no monetary value must be segregated between those which can be sent to ordinary landfill, and potentially contaminated materials, such as insulation, etc., which must be treated as hazardous waste.

If the buildings have no useful purpose and after the equipment has been removed, the buildings and other structures can be dismantled, torn down and/or demolished, with the debris disposed of, for most part, to ordinary landfill.

9.3 Site Restoration:

An extensive soil testing program must be carried out in all the former processing and storage areas. In the typical physical-chemical-biological treatment facility described in this report, all hazardous wastewaters and treated effluent waters are held in tankage. Hence, soil contamination should probably be limited to occasional spills that have seeped into the soil. However, if it is assumed that the facility is at least 20 years old at the time of its decommissioning, there is definitely some potential for soil contamination.

All soil, identified by the soil testing program to be contaminated, must be removed and transported to another hazardous waste treatment facility, for treatment and disposal. The site can then be levelled and is suitable for other land use.

Guideline 9-1: Plans for the decommissioning of the physical-chemical-biological facility should be prepared as a part of the initial planning and design phase. The decommissioning plan should be updated if it is any way affected by changes in facility design or its operating procedures.

Guideline 9-2: The owner or operator of the physical-chemical-biological facility should be required to close the facility in a manner that:

- **minimizes the further need for maintenance.**
- **prevents the escape of any hazardous contaminants to the environment.**

Guideline 9-3: When the plant is decommissioned, all equipment and structures used at the site should be decontaminated or dismantled and disposed of in a safe manner.

Guideline 9-4: The decommissioning plan should provide a description of the activities which should be conducted after final closure of the site. These should include the following:

- **maintaining the functional integrity of the area.**
- **maintaining the monitoring systems.**
- **protection and maintenance of survey or environmental benchmarks.**
- **control of access to the site in accordance with its approved decommissioned use.**

APPENDIX "A"

TYPICAL PROCESS FLOWSHEETS AND MATERIAL BALANCES

A.1 Physical-Chemical Treatment:

The typical process flowsheet for the physical-chemical treatment of inorganic hazardous wastes is shown in Figure 3.0-1. The overall material balance is shown in Table A-1.

Details of the material balances for the inorganic waste streams from Storage A, B and C are as follows:

For purpose of the material balance the inorganic waste stream from Storage A is taken to be a typical rinse water from a Cadmium plating operation.

The waste feed stream would be an aqueous stream containing cadmium cyanide and sodium cyanide. The composition is taken to be 20 mg/L cadmium and 80 mg/L sodium cyanide.

For a batch reactor handling 20 t of waste the material balance would be as follows:

GRAMS/BATCH

	INLET		
Component	**Feed**	**Reactants**	**Effluent**
Water	20×10^6	37 035	20×10^6
$Cd(CN)_2$	585		-
NaCN	1 600		-
NaOCl		7 407	-
NaCl		4 938	10 754
CO_2			1 750
N_2			557
$Cd(OH)_2$			528
NaOH			1 306

TABLE A-1

OVERALL MATERIAL BALANCE - PHYSICAL-CHEMICAL TREATMENT

Component / Stream No.	Grams/day																				
	1	2	3	4	5	6	7	8*	9	10**	11	12	13	14	15	16	17***	18****	19	20	21
Water	20000×10^3	20037×10^3	20000×10^3	20015×10^3	20000×10^3	20016×10^3	20014×10^3	93350	91483	1867	20014×10^3	1867	37035	13000		13446	-	-			
$Cd(CN)_2$	585	-																			
NaCN	1600	-																			
NaOCl													7407								
NaCl		10754											4938								
CO_2		750																			
N_2		557																			
$Cd(OH)_2$		528																			
NaOH		1306																			
H_2CrO_4			5900																		
H_2SO_4			50											3625	-						
$NaHSO_3$														7800							
Na_2SO_4				5325																	
$Cr_2(SO_4)_3$				9800																	
$NiSO_4 \cdot 6H_2O$					4500																
$NiCl_2 \cdot 6H_2O$					600																
$Ca(OH)_2$																1494					
$CaSO_4$						2330	2330				2330										
$CaCl_2$						280	280				280										
$Ni(OH)_2$						1867		1867	-	1867		1867									
Polyelectrolyte								100		100		100						100			
Filter Aid										100		100							100		
Fly Ash												5040								5040	
Lime												1260									1260
Total (Approx)	20002×10^3	20051×10^3	20006×10^3	20030×10^3	20005×10^3	20020×10^3	20016×10^3	95317	91483	3934	20016×10^3	10234	49380	24425	Nil	14940	Nil	100	100	5040	1260

* Taken as 2% Solids
** Taken as 50% Solids
*** Not required for precipitation of Nickel
**** Polyelectrolyte added at rate of 5 ppm

Filter Aid as 5% of solids removed

- This assumes 100% of hypochlorite is reacted and 100% of cyanide is converted to CO_2 and N_2. In practice 100% of cyanide is converted to cyanate and 99.9% of the cyanate is converted to CO_2 and N_2. There is usually a small amount of unreacted hypochlorite in the effluent.

Likewise the stream from Storage B is taken to be typical rinse water from a chromium plating operation.

The waste feed stream would be an aqueous stream containing chromic acid and sulfuric acid. The composition is taken to be 250 mg/L CrO_3 and 2.5 mg/L H_2SO_4.

For a batch reactor handling 20 t of waste the material balance would be as follows:

GRAMS/BATCH

	INLET		
Component	**Feed**	**Reactants**	**Effluent**
Water	20×10^6	13 000	$20\,015 \times 10^3$
H_2CrO_4	5 900	-	-
H_2SO_4	50	3 625	-
$NaHSO_3$		7 800	-
Na_2SO_4			5 325
$Cr_2(SO_4)_3$			9 800

Finally, the stream from Storage C is taken to be a typical rinse water from a nickel plating operation.

The waste feed stream would be an aqueous stream containing nickel sulfate and nickel chloride. The composition is taken to be 250 mg/L $NiSO_4.6H_2O$ and 30 mg/L $NiCl_2.6H_2O$.

For a batch reactor handling 20 t of waste the material balance would be as follows:

GRAMS/BATCH

	INLET		
Component	**Feed**	**Reactants**	**Effluent**
Water	20×10^6	13 446	$20\,016 \times 10^3$
$NiSO_4.6H_2O$	4 500		-
$NiCl2.6H_2O$	600		-
$Ca(OH)_2$		1 494	
$CaSO_4$			2 330
$CaCl_2$			280
$Ni(OH)_2$			1 867

Effluent quality is as set out on Table A-2.

TABLE A-2

EFFLUENT QUALITY

Component	Concentration mg/L
Sulfate	96
Calcium	23
Chloride	11
Nickel	<0.5

A.2 Biological Treatment:

The typical process flowsheet for the biological treatment of organic hazardous wastes is shown in Figure 3.0-2. The overall material balance is shown in Table A-3.

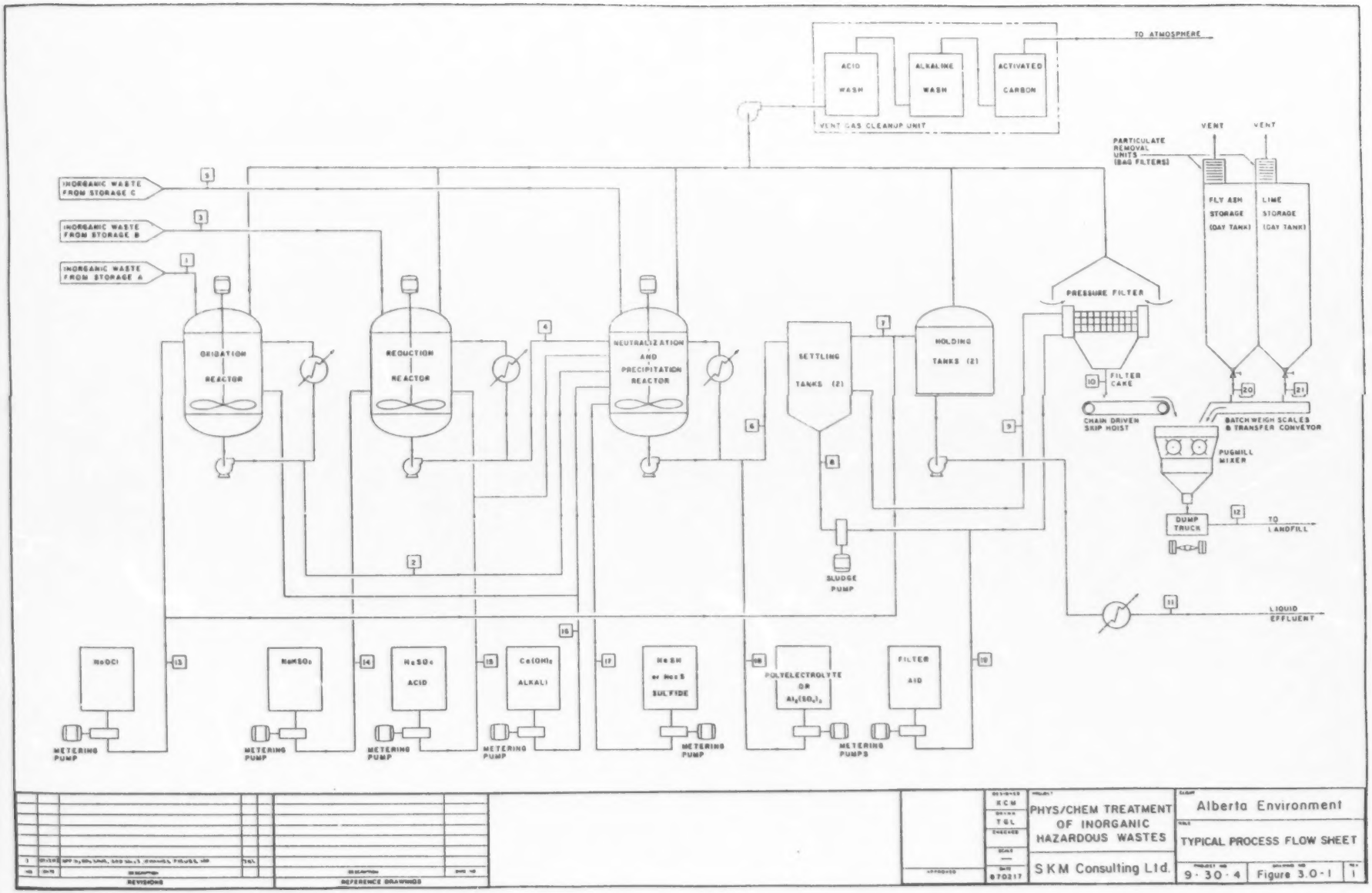
TABLE A-3

OVERALL MATERIAL BALANCE - BIOLOGICAL TREATMENT

Component/ Stream No.	Grams/day											
	1	2	3	4	5	6	7	8	9	10	11	12
Water	60×10^6	14.87×10^6	74.87×10^6	59.97×10^6	17.52×10^6	2.65×10^6		430,000	2.22×10^6		400,000	30,000
BOD	60,000	1,487	7,487	5,997	1,752	265		43	222		40	3
MLSS*		124,988	151,986	4,498	147,488	22,500		22,500				22,500
Polyelectrolyte							15	15				15
Filter Aid										1,200		1,200
Total	60.06×10^6	15.0×10^6	75.03×10^6	59.98×10^6	17.67×10^6	2.67×10^6	15	452,543	2.22×10^6	1,200	400,040	53,718

* Mixed Liquor Suspended Solids

A-5



DESIGNED	KCM	PHYS/CHEM TREATMENT OF INORGANIC HAZARDOUS WASTES
DRAWN	TGL	
CHECKED		
SCALE	—	SKM Consulting Ltd.
DATE	870217	
APPROVED		

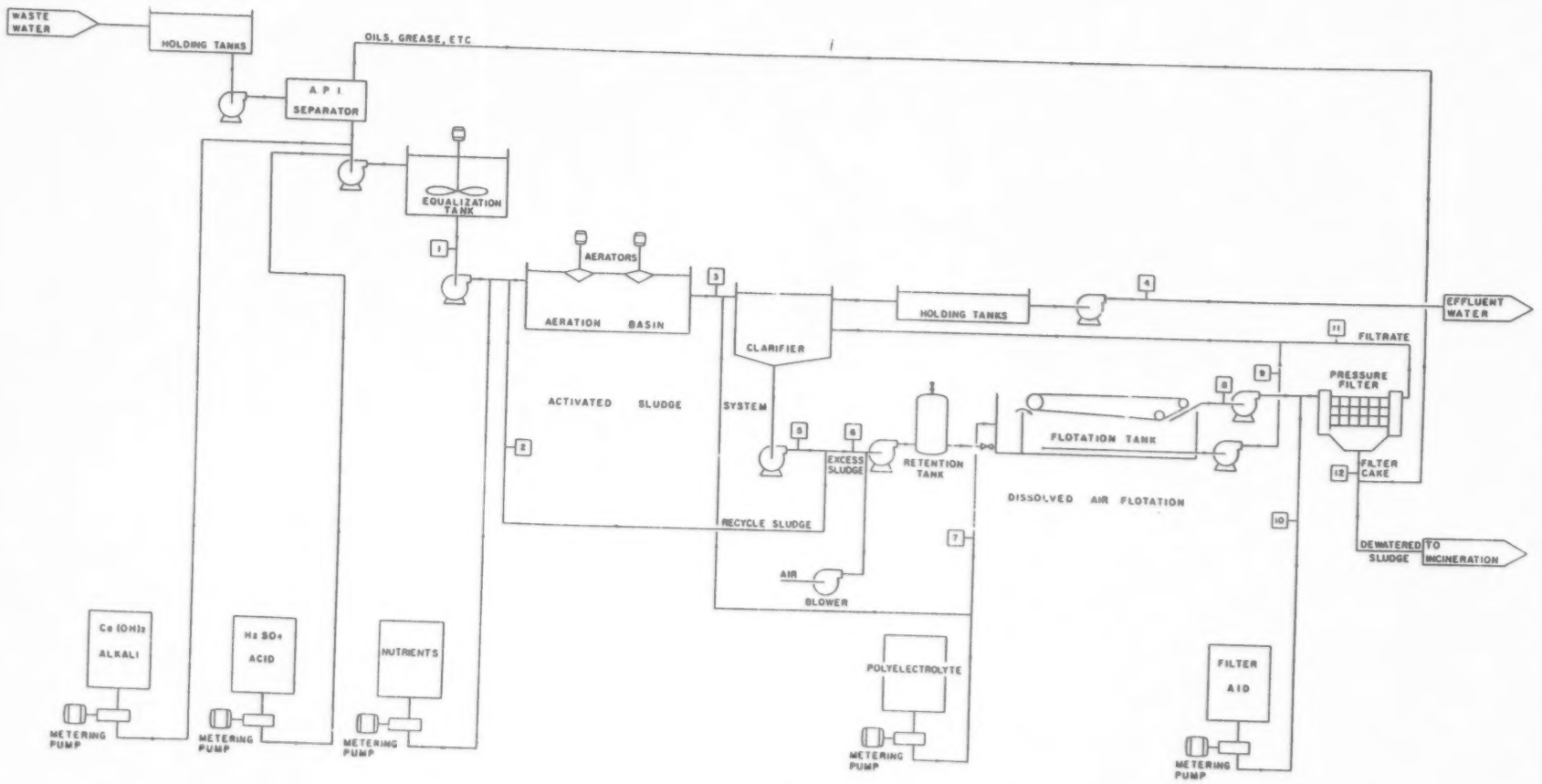
Alberta Environment

TYPICAL PROCESS FLOW SHEET

PROJECT NO. 9-30-4 | DRAWING NO. Figure 3.0-1 | REV. 1

REVISIONS

REFERENCE DRAWINGS



REVISIONS	REFERENCE DRAWINGS	APPROVED	DESIGNED RSG; DRAWN TGL; CHECKED —; DATE 87 11 23	BIOLOGICAL TREATMENT OF ORGANIC HAZARDOUS WASTES	Alberta Environment
			SKM Consulting Ltd.	TYPICAL PROCESS FLOW SHEET	PROJECT NO 9-30-4; DRAWING NO Figure 3-0-2; REV 0

APPENDIX "B"

DESIGN AND OPERATION

B.1 Waste Receiving and Storage:

For the typical physical-chemical-biological treatment facility, described in Section 3.0, it is assumed that the hazardous wastes are received in drums and in bulk tank trucks. The major portion of the inorganic wastes are received in drums, while the majority of the organic wastewaters are received in bulk tank trucks. Drum shipments arriving at the treatment facility are:

- Received at gate
- Unloaded from trucks
- Placed in overpacks if found to be leaking
- Stored in a preliminary segregated fashion
- Thawed if necessary
- Opened as necessary
- Sampled and analyzed
- Covered with a temporary plastic cover as necessary
- Segregated into appropriate batches

Inorganic drums for physical-chemical treatment should be moved to segregated storage areas, and segregated generally in accordance with the following:

- Acid solutions or slurries
- Basic solutions or slurries
- Acid solutions or slurries containing chromate
- Solutions or slurries containing heavy metals
- Basic solutions or slurries containing cyanide
- Drum shipments not in compliance with the accompanying manifest

Drums containing organic wastewaters for biological treatment should also be moved to storage and segregated generally as follows:

- low BOD
- medium BOD
- high BOD
- readily biodegradable organics
- refractory organics
- drum shipments not in compliance with the accompanying manifest

All drums are sampled and analyzed, as well as all bulk tank truck shipments. If the shipment appears to be in compliance with the accompanying manifest, a partial or "fingerprinting" analysis is performed to verify that the hazardous waste is as described in the manifest. If there are any discrepancies between the shipment and the manifest, such as the numbers of drums, or if any of the "fingerprinting" tests fail to verify the information in the manifest, a complete chemical analysis is performed on the shipment. No drums are emptied or tank trucks unloaded until the wastes are positively identified, and their treatability at the physical-chemical-biological facility is confirmed.

The drums are emptied via separate inorganic and organic vacuum systems into surge tanks, from which they are pumped to storage tanks or holding tanks. The inorganic and organic wastewaters are segregated in the storage and holding tanks, generally as outlined above for drums. Vapors from the vacuum systems are discharged to the vent gas cleanup unit.

B.2 Normal Operations:

B.2.1 Physical-Chemical Treatment

2.1.1 General

Key elements or considerations relating to normal operations, normal startup, normal shutdown, and emergency plant operations and shutdown are usually identified in written "plant operating procedures." These operating procedures would typically address operating conditions required for each waste stream in all relevant plant unit operations.

Complete operating procedures for normal operation would typically define the following:

- a recipe for reactants (e.g. concentration, volume of key components)
- charge conditions for reactors covering each processing step (e.g. reactant quantities, pressure, temperature, pH, ORP, cycle times)
- processing conditions for other unit operations
- equipment/piping configuration (e.g. valve positions, requirements for: isolation, purging, inert gas blanketing, venting, rinsing, draining, agitation, recirculation, etc.)
- instrument settings
- batch sampling and product testing requirements
- operation caveats (e.g. maximum concentrations/conditions, completion of reactions, action required in the event of irregular results or conditions)

As previously discussed, the definition of typical inorganic physical- chemical facilities in this report is very broad. Consequently only key processing steps and operating conditions are addressed in the following discussion.

2.1.2 Oxidation

The following steps characterize normal operation of the oxidation reactor circuit for a typical aqueous cyanide waste rinse water from a cadmium plating operation (i.e. stream A):

1) The waste is characterized (by sampling), followed by blending or combination (of like streams) and dilution (if appropriate). The activities all take place in the storage and blending facility upstream of the physical-chemical unit.

2) The waste is pumped from the storage area to the oxidation reactor via a storage area centrifugal transfer pump. Flow is stopped when the normal waste level is sensed in the reactor vessel.

3) Ideally, temperature of the waste batch is preadjusted to ambient temperature (i.e. 15°C to 32°C) by circulating the waste stream through an external heating/cooling loop via the reactor bottoms pump.

4) The reactor agitator is started.

5) The pH of the cyanitic waste batch is adjusted through the addition of an alkali (10-15 wt.% solution of calcium hydroxide) from the semi-automatic alkali feed system. Alkali addition is stopped when the pH of the batch reaches about 9.5 to 10.

6) Oxidant (10-11 wt.% solution of sodium hypochlorite) is metered to the reactor at a predetermined rate allowing good control by the semi-automatic oxidant feed system. Oxidant addition is stopped when an ORP measurement indicates that the end point of the reaction has been reached.

7) Circulation through the external cooling loop is manually initiated early during Step 6 to remove the exothermic heat of reaction liberated and to generally maintain temperatures in the ambient temperature range. Dilution of oxidizable substances, particularly cyanide-containing waste solutions, is desirable to avoid overheating and the release of CNCl gas. Concentrations of CN in the diluted waste feed stream should generally not exceed a few thousand ppm.

8) A timed reaction "soak" period of from 2 to 24 hours is undertaken (with or without external circulation as required) to provide the assurance that complete mixing and oxidation has occurred.

9) If the ORP recorder still shows the oxidation reaction to be incomplete after Step 8, then Steps 5 through 8 can be repeated, as appropriate. If the reaction is clearly complete, then the completely oxidized batch is pumped to the neutralization reactor.

2.1.3 Reduction

The following steps characterize normal operation of the reduction reactor circuit for a typical aqueous stream with a high content of hexavalent chromium (stream B).

1) The waste is characterized (by sampling), followed by blending or combination (of like streams) and dilution (if appropriate). These activities all take place in the storage and blending facilities upstream of the physical-chemical unit.

2) The waste is pumped from the storage area to the reduction reactor via a storage area centrifugal transfer pump. Flow is stopped when high level is sensed in the reactor vessel.

3) Ideally, temperature of the waste batch is preadjusted to ambient temperature (i.e. 15°C to 32°C) by circulating the waste stream through an external heating/ cooling loop via the reactor bottoms pump.

4) The reactor agitator is started.

5) The pH of the normally acidic waste batch is further acidified through the addition of an acid (93 wt.% sulfuric acid) from the semi-automatic acid feed system. Acid addition is stopped when the pH of the batch reaches about 3.0.

6) A reducing agent (35 wt.% solution of sodium bisulfite) is metered to the reactor at a predetermined rate allowing good control by the semi-automatic reduction agent feed system. Reducing agent addition is stopped when an ORP measurement indicates that the end point of the reaction has been reached.

7) Step 5 is periodically repeated to maintain pH of the batch when sodium bisulfite is used as a reducing agent.

8) A timed reaction "soak" period of 15 to 30 minutes is undertaken to provide the assurance that complete mixing and reduction has occurred.

9) If the ORP recorder still shows the reduction reaction to be incomplete after Step 8, then Steps 6 through 8 can be repeated, as appropriate. If the reaction is clearly complete, the completely reduced batch is pumped to the neutralization reactor.

2.1.4 Neutralization and Precipitation

The following steps characterize normal operation of the neutralization and precipitation operation.

a) Treatment for Stream A Wastes

1) The waste is pumped from the oxidation reactor to the neutralization reactor by the reactor bottoms pump.

2) The reactor agitator is started.

3) The pH of the waste batch is adjusted through the addition of alkali (10-15 wt.% solution of calcium hydroxide) from the alkali feed system. Alkali addition is stopped when the pH of the batch reaches the appropriate level where the maximum amount of cadmium is precipitated out of solution as cadmium hydroxide (i.e. normally a pH in excess of 10).

4) Circulation through the external cooling loop is manually initiated early during Step 3 to remove the exothermic heat of reaction liberated during Step 3 and to generally maintain temperatures in the ambient temperature range (i.e. 15°C to 32°C). External cooling, in this manner, may be necessary in the case of neutralization of concentrated solutions of strong bases (or strong acids).

5) A timed reaction "soak" period of 15 to 30 minutes is undertaken to provide the assurance that complete mixing and neutralization has occurred.

6) The waste batch is tested for pH. If the pH is out of the acceptable range, Step 3 is repeated with the addition of either acid or alkali as appropriate, for final pH adjustment followed by Steps 4 and 5. If the pH is acceptable, the neutralized batch is pumped to the settling tank(s).

b) Treatment for Stream B Wastes

1) The waste is pumped from the reduction reactor to the neutralization reactor by the reactor bottoms pump.

2) Same as Step 2 for Stream A above.

3) The pH of the waste batch is adjusted through the addition of alkali (10-15 wt.% solution of calcium hydroxide) from the alkali feed system. Alkali addition is stopped when the pH of the batch reaches an appropriate level where the maximum amount of trivalent chromium precipitates out of solution as chromium hydroxide (i.e. normally a pH in the range from 7 to 8).

4) Same as Step 4 for Stream A above.

5) Same as Step 5 for Stream A above.

6) Same as Step 6 for Stream A above.

c) Treatment for Stream C Wastes

1) The waste is characterized (by sampling), followed by blending or combination (of like streams) and dilution (if appropriate). These activities all take place in the storage and blending facilities upstream of the physical-chemical unit.

2) Same as Step 2 for Stream A above.

3) The pH of the waste batch is adjusted through the addition of alkali (10-15 wt.% solution of calcium hydroxide) from the alkali feed system. Alkali addition is stopped when the pH of the batch reaches an appropriate level where the maximum amount of nickel precipitates out of solution as nickel hydroxide (i.e. normally a pH in excess of 10).

4) A predetermined amount of a precipitation agent (solution of sodium sulfhydrate) may be added to the reactor from the sulfide feed system. This addition allows further precipitation of heavy metals where required to comply with effluent standards.

5) Same as Step 5 for Stream A above.

6) Same as Step 6 for Stream A above.

2.1.5 Gravity Separation

The following steps characterize normal operation of the gravity separation operation:

1) Contents of the neutralization reactor are pumped via the reactor bottoms pump to one of the settling tanks. Concurrently flocculant (aqueous solution of polyelectrolyte) is metered into the settling tank feed stream.

2) The settling tank agitator is started and the contents of the settling tank are gently agitated to allow growth of the flocs of fine particles and near colloidal particles of metal salts thereby promoting their settling characteristics.

3) The agitator is stopped after a short period of time (typically several minutes to 30 minutes) and the flocculated particles are allowed to settle to the tank bottom as sludge. The period of sedimentation following flocculation is highly variable (i.e. 2 to hours) and dependent on several flocculant factors (i.e. molecular weight, dosage, "reaction rate," etc.), and metal precipitate factors (i.e. particle size, presence of other cations, ions, chelating ions, etc.).

4) Sludge settles in the conical section of the settling tanks. Sludge volume is measured by a sludge level indicating device mounted on the settling tank. This device features an ultrasonic transmitter and "non-invasive" sensor/transducer which is not in contact with the process fluids.

5) Once sufficient sludge has accumulated in the settling tank, the pressure filtration loop is put into operation. Filtrate is recycled back from the pressure filter to the settling tank.

6) Clear filtrate from the settling tank is transferred to one of two holding tanks. This liquid is subjected to final testing to verify compliance with water effluent standards.

7) Suitable liquid effluent is pumped from the holding tank through the effluent cooler to the receiving water course. Liquid not meeting effluent standards would have to be returned to the front end of the plant for processing.

2.1.6 Pressure Filtration

The following steps characterize normal operation of the pressure filtration loop:

1) An appropriate aqueous solution of precoat filter-aid is circulated through the pressure filter from the precoat feed system.

2) Sludge from the settling tank is circulated through the pressure filter via the settling tank sludge pump with recirculation of filtrate back to the settling tank. The pump is of the positive displacement type (progressing cavity type) and exhibits pulseless, low shear flow to minimize the potential for breakdown of filter aid precoat and preserve the flocculated condition of the sludge.

3) Concurrently with Step 2, an appropriate aqueous solution of body filter-aid is injected into the inlet slurry feed to the pressure filter to aid in maintaining the porosity of the filter cake.

4) As recesses in the filter plates become filled, filter pressure drop increases. Once pressure drop across the filter becomes excessive (i.e. nominally 60 to 100 psi), the pressure filter is manually depressurized.

2.1.7 Solidification/Stabilization

The following steps characterize normal operation of the solidification operation:

1) Upon completion of the pressure filtration cycle, the filter plates are disengaged and the deposited solids (filter cake) are manually dumped into a transfer bin or

skip hoist bucket. Several dumps of cake may be necessary to accumulate a sufficient volume of solids to warrant subsequent processing.

2) Contents of the transfer bin are weighed on a "tare basis" via a stationary weigh scale.

3) A "standard charge" (predetermined mass) of filter cake is conveyed via skip hoist to the pug mill feed chute and dumped into the pug mill.

4) The pug mill is started.

5a) Fine hydrated lime (1/8" and under) flows from a day tank (equipped with bottom hopper vibrators) via a flow-assisting, variable pitch screw feeder to a batch-type weigh scale.

6a) The batch weigh scale automatically pre-weighs the next mass of lime following dumping of the batch.

7) Lime is gravity dumped into the pug mill on command by the operator.

5b) Fine fly ash (typically minus 100 mesh) flows automatically from a day tank (equipped with bottom hopper aerators) directly to a batch-type weigh scale equipped with an integral weigh hopper.

6b) The batch weigh scale automatically pre-weighs the next mass of fly ash following dumping of the batch.

8) Fly ash is gravity dumped into the pug mill on command by the operator.

9) All components dumped to the pug mill (on a sequenced basis) are mixed for an appropriate time.

10) The mixed material from the pug mill (pozzolan-type cementitious material i.e. "pozzolan cement") is dumped to a bottom-feed flat belt conveyor and conveyed outside the building either to stockpile area or directly to dump trucks.

Notes:

1) The sequence of mixing operations denoted here is hypothetical. Variations should occur in actual practice and be dependent on the nature of the sludge, required additives, etc.

2) Mixing operations described above are manually initiated. The sequencing could also be automated via a time cycle sequencing controller in a similar fashion to batch processing operations in the chemical industry.

3) The "pozzolan cement" typically experiences a hardening reaction. This hardening process transforms the initial silty clay-like consistency to a post-cure consistency similar to that of low- strength concrete. The curing period occurs over a nominal 28 day period.

2.1.8 Vent Gas Cleanup

The following steps characterize normal operation of the vent gas cleanup train.

1) Each of the three vent gas cleanup scrubber systems is designed to be a self-contained package which operates continuously, independent of outside controls during all operational phases of the inorganic physical-chemical plant. Restriction orifices installed at the exit point of each process vessel or tank to the vent system collection header, allow the vent gas cleanup system to operate independent of the operational (or non-operational) status of individual vessels/tanks.

2) Makeup of acid (or alkali solution) to the stage 1 (or stage 2) vent gas cleanup system is accomplished manually on an as needed basis.

3) Draining of contaminant-laden acid wastes (or alkali wastes) from the phase 1 (or phase 2) vent gas scrubber sump is also accomplished manually on an as-needed basis.

2.1.9 Potential Malfunctions

A list o potential malfunctions that could occur in the physical- chemical treatment operations, and the mitigating measures that should be taken, is outlined in Table B-1.

B.2.2 Biological Treatment

The important operating factors in the activated sludge biological treatment process are pH, temperature and toxicity. Depending on the waste, an activated sludge system normally operates at pH values between 6.5 and 9.0. At values below 6.5 and above 9.0 the rate of metabolism normally is retarded. An operating activated sludge process has the capacity to buffer reasonable variations of pH in the incoming wastewater, but it is best if the influent pH is kept between 6.5 and 9.0. In most activated sludge applications the bicarbonate buffer system predominates. The effect of temperature change on the activated sludge process can be significant. An increase of 10°C can double the biological oxidation rate. Slow seasonal changes have less effect, since the biosystem adapts to slow changes occurring in the system within a given range. Within operating range of 10°C to 30°C the range of treatment effectiveness can be adjusted by varying the concentration of microorganisms in the system.

Since the activated sludge process, as opposed to the physical-chemical processes, is a continuous process (except for blending, equalization, etc. in the preliminary treatment, and the periodic cleaning of the filter press), the operations are not so labor intensive as the physical-chemical processes. However, the system must be adequately monitored to ensure a proper environment for the microorganisms, to avoid shock loadings in the aeration basin, and to ensure good liquids-solids separation in the clarifier. The key to the former is efficient waste receiving and storage operations (as described in Section 5.1) to keep heavy metals, cyanides, etc. segregated from the organic wastewater, and efficient operation of the preliminary treatment system.

The use of activated sludge treatment for hazardous organic wastes is perhaps more of a feed inventory and control problem, rather than a process problem. Hence, there is need to employ measures for tight inventory control and front-end management. Generally speaking, the effective operation of the preliminary treatment system involves:

TABLE NO. B-1

RISKS AND MITIGATING MEASURES ASSOCIATED WITH STARTUP, UNLOADING AND STORAGE (HAZARD EVALUATION CHECKLIST)

ACTIVITY	RISK DESCRIPTIONS	MITIGATING MEASURES
START-UP OF PLANT OPERATIONS	- Key equipment instrumentation/safety support/ utility systems are not operational - Isolation/dump valves are not blocked-in - Vessels/tanks have not been drained from previous operations - Sludge lines, filters, pug mill have not been cleaned - Chemical injection facilities have not been charged to suit new operation activities - Pozzolan mix additive tanks have not been charged - Startup bypasses are not operational - Operations/emergency training is incomplete - Operating procedures are incomplete or unavailable - Operators do not have proper protective equipment	- Ensure that operators are thoroughly familiar with all plant equipment and control systems, the hazards involved and have received the necessary operations/emergency training. - Verify that operating procedures, emergency procedures, and startup plans are adequate from personnel safety and pollution abatement points of view.
	- Analysis sheets for waste feed streams are inaccurate or unavailable - Reactor charge sheets are inaccurate or unavailable - Operating instructions, hazardous chemical data sheets, product specifications, etc. are inaccurate or unavailable	- Ensure that operators have access to daily operating instructions, reactor charge sheets, hazardous chemical data sheets, product specification sheets and have completed all necessary pre-operational checks prior to startup. - Identify any waste-specific process hazards including those which could develop under abnormal conditions.
OXIDATION/REDUCTION NEUTRALIZATION	- Escape of hazardous materials due to unanticipated reaction i.e. excess heat or pressure build-up in reactor or over-filling	- Conduct lab simulations beforehand to identify appropriate blending rates and treatability of the waste. - Characterize all waste streams to the unit beforehand. Perform all blending and dilution of streams there. - Prepare reactor charge sheets (recipes) and daily operating instructions for each specific waste.
	- Toxic fumes generated by reaction and released to process vent collection	- Collect and scrub reactor vent exhaust.

TABLE NO. B-1 (cont'd)

ACTIVITY	RISK DESCRIPTIONS	MITIGATING MEASURES
OXIDATION/REDUCTION NEUTRALIZATION (cont'd)		
	- Toxic fumes inadvertently released to process building	- Install toxic gas monitors. - Provide positive air pressure in all working areas with a non recycled ventilation. - Provide appropriate air cannisters or respirators at strategic locations.
	- Leaks from reactor and other vessels threatening surface or groundwater contamination - Leakage from equipment during transfer between process operations	- Segregate and collect all floor spillage in curbed areas and trenches leading to rundown tanks. - Install reactor vessels in a bermed containment area to prevent escape of liquids from leaks or ruptures. - Provide an integrated floor spill treatment capability. - Provide wash down facilities for reactors, tankage, piping, floor areas
	- Inadvertant transfer from unit of hazardous chemicals which are incompletely treated.	- Sample treated wastes prior to discharge to effluent and reprocess, as necessary.
GRAVITY SEPARATION	- See "General - All Operations"	
PRESSURE FILTRATION	- Vent of toxic materials to atmosphere during filter cleaning	- Provide vent hood to collect vapours. Direct vapours to vent gas cleanup.
SOLIDIFICATION/ STABILIZATION	- See "General - All Operations"	
VENT GAS CLEANUP	- See "General - All Operations"	
UTILITY SYSTEMS	- Utility failure e.g. electrical, instrument air - Toxic gas detection - Fire detection	- Plant shutdown - Plant shutdown - Plant shutdown (see also "General - All Operations")

TABLE NO. B-1 (cont'd)

ACTIVITY	RISK DESCRIPTIONS	MITIGATING MEASURES
SOLIDS BULK HANDLING (fly ash, lime) Note: Bulk facilities are adjacent to and not part of the physical-chemical unit	- Spills threatening surface or groundwater contamination - Personnel hazard during handling of lime (e.g. skin contact and respiratory)	- Locate bulk loading and unloading operations in a special area equipped with an impermeable asphalt or concrete pad to facilitate the cleanup of spills. - Utilize pneumatic transfer conveyors for both unloading of dry bulk product and for bulk transfers to operation tanks. - Filter air exhausted from storage bins during bulk transfers using pneumatic conveyors.
STORAGE OF CHEMICAL REAGENTS	- Leaks from in-plant reagent storage tanks or drums threatening surface or groundwater contamination	- Install reagent storage tanks in a special containment area, separate from the process area which prevents escape of liquids in the event of leakage or possible tank ruptures. Conduct routine tank inspections. - Equip each tank with a separate containment berm. - Clearly mark all equipment/piping/ storage facilities handling hazardous materials with placards denoting explosivity, flammability, toxicity, reactivity, corrosivity, as appropriate.
GENERAL - ALL OPERATIONS	- Splashes, inhalation, and spray of toxic materials - or chronic inhalation of background "odours" - Fire in office, laboratory process, storage, offloading areas	- Protective clothing as well as breathing protection. - Thoroughly wash or flush spill area with water and detergent. - Provide separate storage area for drummed reagent material. - Maintain medical surveillance program. - Fire detection. - Provide fire extinguishers, automatic sprinklers, carbon dioxide or foam systems, as appropriate. - Provide isolation of flammable liquid storage facilities by dyking.

- pH control
- blending of influent wastewaters of varying BOD levels, organic constituents and other characteristics to avoid shock loadings
- the dilution of refractory (difficult to biodegrade) organics with ample quantities (say in the order of between 8 and 10 to 1) of readily biodegradable organics
- the avoidance of overloading the activated sludge system, or underloading it to the point of starving the acclimatized mocroorganisms

Since the key to the activated sludge process is the maintenance of a high concentration of microorganisms in the contactor, it is imperative to have efficient liquid-solids separation. One of the major operational problems associated with the activated sludge process is sludge bulking, a condition in which the settling characteristics of the solids are such that liquid-solids separation is inordinately difficult. Among the environmental conditions causing sludge bulking are a high concentration of carbohydrate in the wastewater or a nutrient or oxygen deficiency in the system. The conditions can be rectified if they are quickly identified. Unfortunately, sludge bulking and the factors contributing to it are not always easily identifiable, and periodically excessive loss of solids into the effluent may occur. This requires the recycling of the contents of one or more effluent holding tank, to the equalization tank.

The normal operation of the sludge handling and disposal facilities is relatively straightforward. The operation of the dissolved air flotation unit requires maintenance of the proper air to solids ratio, and polyelectrolyte feed rate. The operation of the filter press is essentially as described in Section 2.1.6.

B.3 Commissioning, Startup and Shutdown Procedures:

B.3.1 Physical-Chemical Treatment

3.1.1 Commissioning

As noted previously, normal startup procedures are usually identified in the written "plant operating procedures." A clear distinction must be made between commissioning (or pre-startup) and startup procedures. Commissioning relates, in general, to functional tests imposed on all mechanical, electrical, instrumentation equipment and systems to verify operability in accordance with the design basis. These functional tests are normally not performed again except as part of a regular safety/operability audit, following a major plant revamp, or as part of problem evaluations. Commissioning of a new plant often includes a preliminary "water run." In this case the equipment is initially operated using pure water, simulating as closely as possible the actual operating conditions, to verify the operation of pumps, agitators, electrical and other utilities, automatic controls, control valves, etc.

Those specific procedures relating to a normal startup for a "cold" unit would typically include the following:

- overall startup sequence of plant facilities
- general caveats or precautions re equipment/instrumentation
- specific startup sequences for utility systems: (i.e. electrical power, instrumentation, cooling water, fuel/inert gas, process sewer/drainage, heat medium)

- specific startup sequences for individual process operations

  Note: that charging of chemicals into process systems is covered in Section B.2.1 — Normal Operations

The following checklist relating to normal startup procedures is very broad in nature and in keeping with the level of definition of the typical physical-chemical plant contained in this report.

3.1.2 Overall Startup Sequence

Plant facilities should be commissioned and started up in the following order:

- general utilities: (electrical power, instrument air, cooling water, fuel/inert gas, heat medium system)
- physical/chemical unit utilities: (vent gas cleanup system, building ventilation, fire detection monitors, toxic gas monitors)

3.1.3 General Equipment/Instrumentation Startup Precautions

- Verify that isolation/dump valves on equipment, vessels, tanks, pumps are closed
- Verify that automatic controls/control valves are operational
- Verify that auxiliary devices on equipment are operational (e.g. pressure/ temperature/level gauges, connections to sensing devices associated with automatic controls)
- Verify the contents of all vessels, tanks, reactors, rundown/drain tanks
- Verify the operational status of equipment requiring periodic manual cleaning, flushing, etc. (e.g. sludge lines, pressure filter plates, pug mill)
- Verify the charge status of chemical injection facilities [e.g. sodium hypochlorite, sodium bisulfite, sulfuric acid, calcium hydroxide, sodium sulfide, flocculant, filter-aid (precoat and body)]
- Verify the charge status of day tanks for pozzolan mix ingredients (e.g. fly ash, lime, retardant, fixative)

3.1.4 Process Facility Startup Considerations

Process facilities should be commissioned and started up generally in the following order and in a sequence corresponding to material flow through the various unit operations:

- Verify analysis sheets for final aqueous waste feed blends (available from Storage/ Blending Area).
- Verify details of reactor charge sheets (planned treatment "recipe" or procedure) for wastes.
- Verify that all operating personnel are equipped with appropriate personal protective equipment and have received daily operating instructions, charge sheets, hazardous chemical data sheets, product specification sheets.
- Preset charge rates and charge times (as appropriate) for the various chemical metering pumps.
- Preset batch weigh scale settings for the various pozzolan mix ingredients corresponding to the "standard mixer charge size"

- Open isolation valves, start circulation pumps in bypass mode (where appropriate) in sequence.

3.1.5 Normal Shutdown Procedures

Normal shutdown procedures are also usually identified in the written "Plant Operating Procedures." Those specific procedures relating to normal shutdown are essentially the same as those defined previously for normal startup, but in reverse order.

Decommissioning of facilities recently shutdown also necessitates the flushing of those equipment items or piping

a) where solids can accumulate and "set-up"
b) where toxic residues would interfere with future processing or be a hazard during maintenance work.

B.3.2 Biological Treatment

3.2.1 Commissioning

As in the case for physical-chemical treatment, the initial commissioning of a new activated sludge facility involves carrying out functional tests of all mechanical, electrical, instrumentation equipment and systems, to verify operability in accordance with the design basis. Utility systems are then activated; in the case of activated sludge this relates primarily to electric power, instrument air and building heating and ventilating, where applicable. Piping is water flushed and all construction debris cleaned from the system.

The entire system is then filled with fresh water to normal operating levels and a "water run" is conducted. This permits the operation of all pumps, agitators, aerators, sludge scrapers/skimmers, air blowers, automatic controls, control valves, etc. under conditions approximating normal loadings in most cases, to verify the proper and trouble-free operation of this equipment. The system is then ready for startup.

3.2.2 Startup Procedures

A new activated sludge facility, or one that has been shutdown for major overhaul or revamp, is usually full of fresh water and must be seeded with live microorganisms. This would also be the case where an operating system had been shutdown long enough for the sludge to become inactive. Seeding can most conveniently be done by using activated sludge from an operating municipal sewage treatment facility, or an industrial wastewater treatment facility. Influent flow is then commenced, with wastewater having BOD and other characteristics most closely approximating that to which the sludge had previously been acclimatized. Influent BOD and other characteristics can then be gradually changed to the desired conditions, as the bacteria become acclimatized. For faster adaption, or to supplement the natural selection process, it is possible to purchase specialized bacteria, usually freeze-dried, to seed or periodically supplement the activated sludge.

3.2.3 Shutdown Procedures

Minor shutdowns, not requiring the emptying of the system, can be carried out by shutting down the flow of influent wastewater, and hence effluent water and excess sludge, in which case recycle sludge flow and/or aeration can be continued or stopped, depending on the reason for the shutdown and/or the equipment requiring maintenance.

For major overhauls and revamp work, where the system is to be emptied of water and sludge, recycle sludge flow and aeration can be discontinued, and fresh water substituted for the influent wastewater flow. This should gradually displace the sludge from the aeration basin to the clarifier, from which it is removed from the system via the excess sludge handling and disposal facilities. The clarifier overflow quality should deteriorate, and necessitate the recycle of waters from the effluent holding tanks to the influent wastewater holding tanks. After removal of the sludge from the system, the water contents are also transferred to the influent wastewater holding tanks.

B.4 Emergency Operations/Shutdown:

B.4.1 Physical-Chemical Treatment

4.1.1 General

Any discussion of emergency procedures, especially those that result in forced or emergency shutdowns, must first address the various protective systems or features incorporated in the plant design. Protective systems and features required are dependent on plant operating philosophy. Some of the important issues are:

- The basic process arrangement (i.e. batch, semi-continuous or continuous)
- The number of operating hours — daily and weekly (i.e. discontinuous, continuous)
- The level of operator attendance (i.e. semi-attended or fully attended)
- The nature of instrumentation/controls (i.e. automatic or interactive, routine services instrumented or critical services only instrumented)
- Plant arrangement (i.e. partially outdoors or fully enclosed)

Definition of plant protective systems invariably involves trade-offs wherein capital costs, operating costs, the level of operator interaction desired, the degree of personnel hazard, the degree of environmental hazard, sophistication of the operating company, etc. influence the extent of automatic controls and level of protective systems provided.

The operating philosophy of the typical physical-chemical plant facilities described in this report can be characterized by the following:

- batch process arrangement
- 24 hour/day, 5 day/week operation
- full operator attendance
- automatic instrumentation provided only for critical services
- plant facilities fully indoors
- careful attention to protective systems

4.1.2 Protective Systems and Features

Typical protective systems and features for this operation consist of the following:

a) Fire Protection

- Covered in Section 8.0.

b) Pressure (and vacuum) Relief

- Relief valves are provided on all reaction vessels and tanks and vented to rundown tanks. Rupture discs located upstream of relief valves provide isolation of valve parts from corrosive vent streams under normal operating conditions, yet impose little rupture resistance during over-pressure relief circumstances.
- Relief valves are provided on the discharge side of positive displacement pumps and vented to the suction tank.

c) Containment

- Reactant storage is located in the main process area.
- All process vessels and tanks are separately diked, including those contained within buildings; floor drains are directed to rundown tankage.
- The design provides for containment of leaks from equipment (e.g. pump seals) and piping where liquids which pose a personnel hazard or pollution potential are handled.
- Pressure-rated gauge glass assemblies are provided where visual level indication of toxic liquids is required.
- Appropriate materials of construction are provided in all process and additive systems to minimize corrosion, erosion, stress corrosion, and metal fatigue which could cause unplanned leaks, failures, or undesirable accumulations of corrosion products.

d) Process Interlock/Trip Systems

Interlocks can generally be categorized as follows:

A) alarm - visual/audible alarm
B) sequential - imposes a prescribed sequence of events
C) permissive - imposes preconditions before action can be taken *or* for action to continue
D) protective - aborts normal operation *or* causes equipment shutdown/ depressurization, etc. where equipment damage would otherwise result
E) safety - aborts normal operation *or* causes equipment shutdown/ depressurization, etc. where injury to personnel *or* pollution would otherwise result
F) emergency - imposes full shutdown of plant operations shutdown including all equipment where widespread personnel injury, pollution and equipment damage would otherwise result

The following Table No. B-2 provides broad examples of operation irregularities together with the typical interlock category and shutdown or corrective action which would result for the typical inorganic physical-chemical plant discussed in this report. For the typical fully operator-attended plant such as this, unplanned operational irregularities usually result in an alarm condition, but not always. When an alarm condition only results, the operator has the opportunity to correct the condition without shutting the plant down unnecessarily. Severe irregular conditions, on the other hand results in a forced equipment or plant shutdown condition depending on the severity of the condition.

B.4.2 Biological Treatment

Generally speaking the activated sludge process of biological treatment is less complex than physical-chemical treatment, and less prone to emergency operations and/or emergency shutdowns.

The primary causes of emergency operation and/or shutdown in an activated sludge system are shock loads such as:

- pH shocks
- heavy metal or cyanide shocks
- BOD shocks
- refractory organic shocks

In each case the effect of the shock loads would be to inhibit microbiol metabolism, resulting in poor BOD removal and/or excess carryover of suspended solids (unsettled microorganisms) in the effluent wastewater. Corrective action would be to shut off the flow of influent wastewater from the equalization tank, and to recycle any off-quality waters from the effluent holding tanks to the equalization tank and/or influent wastewater holding tanks. The cause of the shock must be corrected by blending and/or pH adjustment in the equalization tank, or should the equalization tank contain high levels of heavy metals or cyanides, it may be necessary to segregate these waters for prior physical-chemical treatment.

Another cause of emergency operation involving recycling of effluent water to the equalization and/or influent holding tanks is sludge bulking, resulting in excessive sludge retention in clarifier and carryover of suspended solids.

B.5 General Safety:

The initial phase of a general safety program is hazard recognition that identifies problem areas. A number of general safety and security measures can be implemented for reducing risks to human health and the environment at a physical-chemical-biological facility:

- Alarm buttons should be located at critical areas in the facility. These buttons should sound an audible alarm on the site and provide a visual indication on the operator panel, identifying where the trouble is located so that immediate response can be undertaken.
- Provision of an effective security fence around the site. Hiring of security guards is warranted if vandalism or break-in problems are anticipated.

TABLE NO. B-2 UNPLANNED/EMERGENCY OPERATION/SHUTDOWNS - PHYSICAL/CHEMICAL TREATMENT

ACTIVITY	IRREGULARITY	INTERLOCK CATEGORY	AUTOMATIC ACTION	OPERATOR ACTION
OXIDATION				
Waste transfer from storage	- High reactor level	Safety	- Transfer pump stoppage	
Oxidation of waste	- High reactor temperature	Protective	- Oxidant pump stoppage	- External cooling of batch
	- Agitator stoppage	Alarm		- Repair/start agitator
	- High reactor pressure	Protective	- Oxidant pump stoppage - Relief valve activation	- Dump batch to rundown tank (optional)
	- Continuing low pH	Safety		- Investigate equipment malfunction
	- High oxidant feed pump pressure	Protective	- Relief valve activation	- Investigate piping blockage
Waste transfer to neutralization	- High pump discharge pressure	Protective	- Alarm	- Investigate piping blockage
pH adjustment of waste	- High alkali feed pump pressure	Protective	- Relief valve activation	- Investigate piping blockage
	- Agitator stoppage	Alarm		- Repair/re-start agitator
Recycle cooling/heating	- High exchanger differential pressure	Alarm		- Investigate exchanger blockage
REDUCTION				
Waste transfer from storage	- High reactor level	Safety	- Transfer pump stoppage	
Reduction of waste	- High reactor temperature	Protective	- Reduction pump stoppage	- External cooling of batch
	- Agitator stoppage	Alarm		- Repair/start agitator
	- High reactor pressure	Protective	- Reductant pump stoppage - Relief valve activation	- Dump batch to rundown tank (optional)
	- Continuing high pH	Safety		- Investigate equipment malfunction

TABLE NO. B-2 (cont'd)

ACTIVITY	IRREGULARITY	INTERLOCK CATEGORY	AUTOMATIC ACTION	OPERATOR ACTION
REDUCTION (cont'd)				
	- High reductant feed pump pressure	Protective	- Relief Valve activation	- Investigate piping blockage
Waste transfer to neutralization	- High pump discharge pressure	Protective	- Alarm	- Investigate piping blockage
pH adjustment of waste	- High acid feed pump pressure	Protective	- Relief valve activation	- Investigate piping blockage
	- Agitator stoppage	Alarm		- Repair/re-start agitator
Recycle cooling/heating	- High exchanger differential pressure	Alarm		- Investigate exchanger blockage
NEUTRALIZATION/ PRECIPITATION				
Waste transfer to neutralization	- High reactor level	Safety	- Transfer pump stoppage	
Neutralization of waste	- High reactor temperature	Protective	- Acid pump stoppage	- External cooling of batch
	- Agitator stoppage	Alarm		- Repair/start agitator
	- High reactor pressure	Protective	- Acid pump stoppage - Relief valve activation	- Dump batch to rundown tank (optional)
	- Continuing hi/low pH	Safety		- Investigate equipment malfunction
	- High acid/alkali feed pump pressure	Protective	- Relief valve activation	- Investigate piping blockage
Waste transfer to settling tank	- High pump discharge pressure	Protective	- Alarm	- Investigate piping blockage
Recycle cooling/heating	- High exchanger differential pressure	Alarm		- Investigate exchanger blockage

TABLE NO. B-2 (cont'd)

ACTIVITY	IRREGULARITY	INTERLOCK CATEGORY	AUTOMATIC ACTION	OPERATOR ACTION
GRAVITY SEPARATION				
Waste Transfer from Neutralization	- High settling tank level	Safety	- Transfer pump stoppage	
	- High precipitation agent pump pressure	Protective	- Relief valve activation	- Investigate piping blockage
PRESSURE FILTRATION				
Normal filtration cycle	- High filter pressure (abnormal)	Alarm	- Sludge pump stoppage	- Clean filter
	- High precoat pump pressure	Protective	- Alarm	- Investigate blockage
	- High admix pump pressure	Protective	- Alarm	- Investigate blockage
SOLIDIFICATION/ STABILIZATION				
Normal mixing cycle	- Mixer motor overload	Protective	- Mixer motor stoppage	- Investigate overload
	- Discharge conveyor overload	Protective	- Conveyor motor stoppage	- Investigate overload
VENT GAS CLEANUP				
Normal operation	- Vent gas system shutdown	Safety	- Alarm	- Investigate equipment malfunction
	- Toxic vent gas effluent	Safety	- Vent gas system stoppage	- Investigate equipment malfunction
UTILITY SYSTEMS				
	- Electrical power failure	Protective & Safety	- Plant shutdown - Emergency power generation start	- Block-in plant systems in anticipation of plant restart
	- Building fire detector	Emergency	- Plant shutdown - Fire extinguishing system activated - Building fans shutdown	- Extinguish small fires - Escape building - large fire
	- Building toxic gas detection	Emergency	- Plant shutdown	- Escape building

TABLE NO. B-2 (cont'd)

ACTIVITY	IRREGULARITY	INTERLOCK CATEGORY	AUTOMATIC ACTION	OPERATOR ACTION
UTILITY SYSTEMS (cont'd)				
	- Low instrument air pressure	Emergency	- Plant shutdown	
	- Undefined Emergency	Emergency		- Plant shutdown
	- Heat medium system failure	Alarm		- Investigate equipment malfunction
	- Cooling water system failure	Alarm		- Investigate equipment malfunction
GENERAL - ALL OPERATIONS				
Normal operations	- Leakage of toxic materials	Safety		- Shutdown pump, block-in leaking system, dump tanks to drain system as appropriate

Note: all irregularities typically initiate an alarm on a "first out" basis

- Radio or telephone communication should be established between remote areas of the site or plant. Operators at remote locations should check-in via voice communication to central operations or control station.

B.6 Personnel Protection and Training:

Listed below are classes of noxious substances grouped according to their acute metabolic or physiological activity.

Irritants: Corrosive or vesicant (blister-causing) materials that attack the eyes, mucous membranes and respiratory tract.

Asphyxicants: Substances (usually gases) that prevent or hinder blood from transporting oxygen. There are two main types; simple asphyxiants such as carbon dioxide or nitrogen or chemical asphyxiants that irreversibly react with the hemoglobin preventing its oxidative — reductive respiratory function.

Anesthetics and narcotics: Substances that depress the central nervous system by various means.

Systematic poisons: Such as heavy metals and arsenic that cause tissue damage usually in a specific organ.

Respirable particulates: A material that places a burden on lung efficiency such as dust or aerosols.

A number of protective and safety measures can be implemented for the operating personnel at the plant. These are:

a) The provision of protective apparel such as rubber, neoprene, or plastic gloves, boots, and isolation suits. Goggles, face shields, air packs, and first aid equipment must be located at strategic locations.
b) Eye wash and shower stations should be located at convenient points throughout the facility.
c) Separate "Dirty" and "Clean" change rooms complete with lockers should be provided, separated by a shower or washup facility. Contaminated clothing worn by workers on the site remains in the appropriate room thereby reducing the risk of any contamination leaving the site.
d) Provision of workers or employee training programs to include:
   - properties of hazardous waste and hazardous materials
   - compatibility and chemistry of hazardous materials and hazardous wastes
   - safety training
   - spill and fire response training
   - first aid
e) A thorough pre-employment medical examination should be implemented with subsequent follow-up examinations on a six to twelve month basis.

B.7 Maintenance Procedures:

B.7.1 General

Routine maintenance considerations for process facilities in a typical physical-chemical-biological treatment plant are broadly described in the following discussion. These considerations relate to equipment, piping and instruments and are categorized as follows:

- Safe work practices (common to all)
- Process safety items (common to all)
- Equipment maintenance (major equipment categories)
- Short term (daily, weekly, or on demand)
- Turnaround (i.e. semi-annually or longer)

a) Safe Work Practices
   - Precautions for major maintenance work or hot work (cutting and welding) include the following:
     - preparatory items: depressurization, draining, water flushing, steaming or air purging of vessels/tanks (for toxic/corrosive chemical service)
     - personnel safety items: goggles, face masks, rubber gloves, aprons, fume hood (and/or self-contained breathing apparatus), all as appropriate
     - hazardous work procedures: lock-out of electrical switchgear/ electric motor push buttons/valves, piping line blocks, enclosed space entry requirements (e.g. continuous air purging, safety lines, outsider work attendance ("buddy approach"), scaffolding, semi-continuous gas testing
   - Personnel safety equipment
     - recalibrate automatic/portable equipment used for detection of noxious or combustible gases
     - regularly check the operational status of personal protective equipment, fire hoses, sprinkler systems

b) Process Safety Equipment and Appurtenances
   - Short term
     - inspect building ventilators
   - Turnaround
     - shop test safety relief valves for the correct relieving pressure and for tightness; reset and refurbish
     - examine rupture discs (upstream of safety valves) for stress cracking and corrosion: replace as necessary
     - check out emergency shutdown systems, electrical interlocks, alarm devices, instrument purge systems
     - reweigh and recharge CO2 fire extinguishers

c) Non-code Vessels and Tanks, Piping
   - Short term

- check that vent lines (and restriction orifices) to vent gas cleanup system are clear
- check flanged joints and packed valves for leakage; replace gaskets/packing/valve seats and tighten as required
- verify that check valves are operational and sealing properly; replace or refurbish as necessary

- Turnaround
  - spot check metal thickness for corrosion (ultrasonic or other appropriate non-destructive testing method); reclad as necessary
  - spark test plastic-lined vessels to verify the integrity of the lining; spot repair
  - check exterior/exterior coating for corrosion

d) Centrifugal/Slurry/Rotary Pumps, Agitators, Aerators, Air Blowers
- Short term
  - tighten, repack and lubricate leaking stuffing boxes
  - check relief valves on rotary pumps
  - lubricate bearings
  - check aerator gearbox lubricant levels; add as necessary

- Turnaround
  - check mechanical seals for corrosion and wear; checkout and repair flushing/balancing systems where double seals are used
  - check pump wearing rings and impellers for wear and corrosion; replace as necessary
  - check straightness of agitator shafts, security of impeller mounting and corrosion of impellers
  - inspect aerator reduction gears

e) Reciprocating Pumps, Metering Pumps
- Short term
  - tighten, repack and lubricate leaking packing glands
  - lubricate

- Turnaround
  - test check valves for leak tightness and discharge relief valves for leak tightness and set pressure; repair or repair and reset

f) Heat Exchangers
- Short term
  - back flush to remove accumulated sediment

- Turnaround
  - clean badly-fouled exchangers using either acid wash (in place) or high pressure water (disassembled) techniques

g) Pressure Filter
- Short term
  - examine filter cloth for holes after each cycle; recloth as necessary

- Turnaround
  - refurbish interleaf gaskets as necessary to minimize leaking

h) Solids Handling Equipment

Skip Hoist, Belt Conveyors
- Short term
  - examine guide rolls/tracks, guide pulleys, tensioning devices for alignment; adjust as necessary
  - inspect conveyor belt for wear; repair as necessary
  - inspect skip hoist chain/anchoring system; tighten and adjust
  - lubricate/grease bearings and moving parts
- Turnaround
  - replace bearings, idlers, conveyor belt as necessary
  - repair/replace track, hopper for skip hoist as necessary

Pug Mill
- Short term
  - clean hardened sludge residues from mill components
  - check wearing parts, paddles for integrity and wear
  - verify the integrity of mill seals
- Turnaround
  - examine entry/discharge doors, paddles, reduction gears, etc. for wear and alignment; repair as necessary

Batch Weigh Scale Systems
- Short term
  - verify/recalibrate beam balance mechanism
  - verify integrity of chute joints/flexible connections; repair leaks
  - remove accumulated dust from scale components
- Turnaround
  - check functioning/repeatability of time cycle controller components, refurbish scale wearing parts

Day Tanks
- Short term
  - ensure top-mounted exhaust gas filter assemblies are clean and functional
  - verify that flow inducers (aerators, vibrators) are operational; replace or repair as necessary
- Turnaround
  - inspect/repair screw feeders, chuting for wear and leak-tightness

i) Vent Gas Cleanup Equipment
- Short term
  - periodically drain contaminated acid wash and alkaline wash sump fluids to rundown tanks for reprocessing; refill sumps with fresh wash fluid

- verify proper functioning of acid wash and alkaline wash package equipment (i.e. pumps, spray system, sumps, etc.

- Turnaround
  - replace carbon bed adsorbent en masse
  - verify proper functioning of acid wash and alkaline wash spray nozzles
  - inspect all vent gas cleanup trains for corrosion; refurbish as necessary

j) Instrumentation/Electrical Systems
- Short term
  - clean gauge glasses
  - remove incrustations from pH probes (due to water hardness, precipitates)
  - operate valves exposed to buildup of scale or corrosion products to prevent freeze-up
  - clean temperature gauges probes instrument taps subject to pluggage (e.g. pressure gauges/sensors, gauge glasses, orifice- flow meters, level sensor float chambers
  - clean rotameter tubes
  - check calibration of analytical instrumentation (e.g. zero setting of pressure and flow transmitters, level sensors versus pressure gauges, temperature gauges, etc.

- Turnaround
  - recalibrate orifices and gas and liquid flow meters
  - repack control valves and check adequacy of trim
  - verify that control valves, regulators, etc. should fail-safe in event of instrument air or electrical failure
  - verify the integrity of plant grounding and electrical bonding systems

B.8 Toxic Fume Control:

Toxic fume control is required for the physical-chemical-biological treatment facilities only. No toxic fumes are evolved from the activated sludge process, and the normal practice is to locate the major components (aeration basin and clarifier) out of doors. The relevant features of toxic fume control for physical-chemical-biological treatment are as follows:

- Building ventilation is provided to keep concentrations of toxic vapours below the threshold limit value (TLV); ventilation is maintained at a minimum 10 air changes/hour. Ventilation is of the once-through type (i.e. without recirculation).
- All process vessels and tanks (including rundown tanks) are permanently vented to the vent gas cleanup system equipped with restriction orifices at the header entrance points to equalize resistance to flow in all vent lines (especially vent hood vent lines) and to maintain a slight negative pressure in the vent system. This permits continuous operation of the vent gas cleanup system regardless of the operational status of individual vessels/tanks, vent hoods, etc. and prevents the escape of noxious fumes from the system.
- Vent hoods are provided at all locations involving manual loading/ unloading of toxic dusts/vapours (e.g. pressure filter, toxic solid reagent dump points). Vent hoods are connected to the vent gas cleanup system.

The vent gas cleanup system is composed of the following equipment:

- Acid wash scrubber system — packaged system consisting of a scrubber vessel with integral bottom sump to hold acid wash liquid solution, centrifugal wash pump and associated controls.

  Packed scrubber vessel features upward flow of waste-contaminated gases and downward directed spray of acid solution at the top of the tower. The initial acid solution spray followed by counter-current washing within the packed bed removes air-borne contaminants by absorption and reaction with the acid.

  Liquid/precipitate accumulations in the bottom sump are periodically drained to the appropriate reactor. Acid solution makeup is provided from the acid feed system with appropriate water dilution.
- Alkaline wash scrubber system — packaged system similar in function and features to the acid wash scrubber system. Alkaline solution makeup is provided from the alkali feed system with appropriate water dilution.
- Activated carbon scrubber system — packaged carbon adsorption system consisting of multiple parallel adsorbers (one operative at a time). This system is used as a polishing vent gas scrubbing device following the other scrubbers. Carbon usage is expected to be small hence regeneration is not economical and carbon is replaced after a period of use. Spent carbon is drummed and sent to an incinerator facility for disposal.
- Common vent gas fan and drive — provides motive power for drawing gaseous waste vent gas flows from all plant process vessels and tanks, pressure filter fume hood, etc. successively through the acid wash scrubber, alkaline wash scrubber and the activated carbon scrubber. Clean effluent air is discharged to the atmosphere.

APPENDIX "C"

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APPENDIX "D"

PHYSICAL-CHEMICAL-BIOLOGICAL TREATMENT PROCESSES (Source: Shuckrow et al)

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
Antimony		
Activated carbon adsorption	0-33	1.3-590
granular		
ozone		
Chemical precipitation with sedimentation		
lime	40-99	ND-180
polymer unspecified	28	18
sodium carbonate	84	15-57
Coagulation and flocculation	51	10-120
Filtration	0-92	BDL-700
Flotation	4-95[a]	ND-2,300
Reverse osmosis	10-60	1-200
Sedimentation	0-86	2-1,000
Activated sludge	33-90	BDL-670
Lagoons (aerated)	82-99	ND-30
Arsenic		
Activated carbon adsorption (granular)	0-99	1-42
Chemical oxidation (ozone)	0-48	BDL-43
Chemical precipitation with sedimentation		
lime	20-99	ND-110
alum	0	62-62
barium chloride	33	2
FeCl(3)	75	1
sodium carbonate	96	10-68
combined precipitants	25-99	ND-3
Chemical precipitation with filtration	33	4.0
Coagulation and flocculation	40-92	BDL-62
Filtration	0-99	BDL-100
Flotation	8-99	ND-18
Reverse osmosis	57-99	1-49
Sedimentation	0-99	BDL-230
Activated sludge	20-98	BDL-160
Lagoons (aerated)	99	ND-20
Asbestos (Total)		
Chemical precipitation with sedimentation		
lime	95	6.1E6-2.3E9[a]
barium chloride	75	5.7E8[a]
Filtration	90	4.7E8[a]
Sedimentation	75-99	1.9E7-3.3E10[a]
Asbestos, Chrysotile		
Sedimentation	95-99	3.3E5-1.5E4[a]
Beryllium		
Chemical precipitation with sedimentation		
polymer/unspecified	33	4
sodium carbonate	75	1-11
combined precipitants	80-99	ND-10
Chemical precipitation with filtration	0	1.0
Filtration	0-7	0.02-10
Reverse osmosis	85	0.5-5
Sedimentation	0-98	0.9-20
Activated sludge		BDL-BDL
Lagoons (aerated)	50	1
Cadmium		
Activated carbon adsorption (granular)	76-95	1.5-40
Chemical precipitation with sedimentation		
lime	0-99	ND-80
alum	38-88	12-47
polymer/unspecified	0-99	5-100
sodium carbonate	67-99	1-5
sodium hydroxide	22-99	ND-930
combined precipitants	11-99	ND-80
Chemical precipitation with filtration	0-99	ND-19
Coagulation and flocculation	99	BDL-10
Filtration	0-99	ND-97
Flotation	0-99[b]	BDL-72
Oil separation	98	BDL-200
Reverse osmosis	0-60	0.5-48
Sedimentation	0-99	BDL-200
Ultrafiltration	67-93	BDL-200
Activated sludge	0-99	BDL-13
Lagoons (aerated)	97	2
Chromium		
Activated carbon adsorption granular	10-95	4-260

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
powdered	3-97	24-110
Chemical precipitation with sedimentation		
lime	47-99	ND-18,000
alum	13-93	31-170,000
barium chloride	50	25
polymer/unspecified	74-99	5-790,000
sodium carbonate	99	27-430
sodium hydroxide	53-99	18-3,000
combined precipitants	33-99	ND-2,500
Chemical precipitation with filtration	50-99	5.0-2,200
Chemical reduction	18-99	90-130,000
Coagulation and flocculation	72-99	17-1,300
Filtration	0-99	4-320
Flotation	20-99	2-620
Neutralization	99	40
Oil separation	82-98	9-240
Reverse osmosis	3-95	1-900
Sedimentation	0-99	BDL-30,000
Ultrafiltration	67	68-2,900
Activated sludge	5-98	BDL-20,000
Lagoons		
aerated	0-99	9-1,100
non-aerated	99	ND
Rotating biological contactors		
Copper		
Activated carbon adsorption		
granular	13-85	4-360
powdered	61-96	5.5-29
Chemical oxidation		
chlorine	14	320
ozone	12	88-590
Chemical precipitation with sedimentation		
lime	29-100	ND-220
alum	30-99	ND-270,000
barium chloride	50	20
polymer/unspecified	0-99	4-2,200,000
sodium carbonate	83	48-1,300
sodium hydroxide	36-98	1-5,900
combined precipitants	43-99	4-400
Chemical precipitation with filtration	14-99	16-1,700
Chemical reduction	21-89	BDL-15
Coagulation and flocculation	35-99	10-80
Filtration	0-99	4-4,500
Flotation	9-98	5-960
Neutralization	98	30
Oil separation	93-99	BDL-450
Reverse osmosis	29-93	9-28,000
Sedimentation	0-99	ND-660
Ultrafiltration	44-90	BDL-1,100
Activated sludge	2-99	BDL-170
Lagoons (aerated)	26-94	7-110
Cyanides		
Activated carbon adsorption		
granular	1-90	2-52
powdered	50-69	20-45
Chemical oxidation		
chlorine	86-99	2-130
ozone	33-98	2-95
Chemical precipitation with sedimentation		
lime	67-99	ND-5,500
alum	60	2-120
polymer/unspecified	0-99	BDL-5,200
Chemical precipitation with filtration	60	BDL-5
Coagulation and flocculation	0-99	3-260
Filtration	0-62	10-2,300
Flotation	13	BDL-13
Oil separation	23-91	1-2,200
Reverse osmosis	20-90	BDL-4,500
Sedimentation	60	51,000
Stripping (air)	0-99	ND-38,000
Activated sludge	91-99	ND-150
Lagoons (aerated)	79	16
Trickling filters		
Lead		
Activated carbon adsorption (granular)	2-72	18-79
Chemical oxidation (ozone)	29	22-900
Chemical precipitation with sedimentation		
lime	0-99	ND-580
alum	0-96	28-140,000

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
polymer/unspecified	26-99	BDL-1,000
sodium carbonate	94-99	15-1,900
sodium hydroxide	99	ND
combined precipitants	0-99	ND-230
Chemical precipitation with filtration	81-99	ND-68
Chemical reduction	25-67	62-120,000
Coagulation and flocculation	0-99	BDL-100
Filtration	3-99	BDL-2,100
Flotation	9-99	ND-1,000
Oil separation	97-99	BDL-600
Reverse osmosis	0-96	1-520
Sedimentation	0-99	ND-6,800
Ultrafiltration	44-95	BDL-1,000
Activated sludge	10-99	ND-120
Lagoons		
aerated	80-99	ND-80
non-aerated	99	ND
Mercury		
Chemical precipitation with sedimentation		
lime	69-96	0.1-13
alum	6-93	1.7-4,000
barium chloride	87	0.5
polymer/unspecified	0-7	1-26
combined precipitants	0-97	0.2-980
Chemical precipitation with filtration	67	0.1
Coagulation and flocculation	10	0.3-1
Filtration	0-89	0.1-2,900
Flotation	33-88	BDL-2
Oil separation	80	BDL-2
Reverse osmosis	60	0.1-1
Sedimentation	0-97	BDL-84
Ultrafiltration	0-33	0.4-2
Activated sludge	33-94	ND-0.9
Lagoons (aerated)	99	0.1-1.6
Nickel		
Activated carbon adsorption (granular)	10-68	BDL-700
Chemical precipitation with sedimentation		
lime	6-99	ND-5,200
alum	0-98	1.0-51,000
polymer/unspecified	8-99	5-6,400
sodium carbonate	96	18-640
sodium hydroxide	99	ND-210
combined precipitants	0-99	ND-10,000
Chemical precipitation with filtration	47-99	ND-1,700
Coagulation and flocculation	82-99	BDL-2,500
Filtration	0-99	BDL-700
Flotation	29-99	ND-270
Neutralization	99	20
Oil separation	96	BDL-500
Reverse osmosis	9-89	1-210
Sedimentation	0-99	BDL-2,000
Ultrafiltration	32	10-500
Activated sludge	0-99	ND-400
Lagoons (aerated)	0-50	5-40
Selenium		
Activated carbon adsorption (granular)	0-50	1-50
Chemical oxidation (ozone)	99	ND-1
Chemical precipitation with sedimentation		
lime	0-99	ND-87
sodium carbonate	96	4-280
combined precipitants	0-13	2-7
Filtration	0-10	BDL-100
Reverse osmosis	67-85	1-6.1
Sedimentation	0-98	2-32
Lagoons		
aerated	50-99	ND-200
non-aerated	44	18
Silver		
Activated carbon adsorption (granular)	12-36	1.7-100
Chemical precipitation with sedimentation		
lime	20-99	ND-90
alum	21	7-170
polymer/unspecified	0-67	12-35
sodium carbonate	97	2-22
sodium hydroxide	6	11-64
combined precipitants	9-43	0.4-10

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
Chemical precipitation with filtration	40-78	4.5-34
Coagulation and flocculation	10	1-72
Filtration	0-91	BDL-100
Flotation	45	BDL-66
Reverse osmosis	0-92	0.2-78
Sedimentation	0-96	1-100
Activated sludge	3-99	BDL-95
Thallium		
Chemical precipitation with sedimentation		
lime	58-75	1-20
sodium carbonate	99	41
Chemical precipitation with filtration	0	50
Chemical reduction	94	1
Reverse osmosis	50-99	1-4
Sedimentation	0-83	2-100
Activated sludge		BDL-BDL
Lagoons (aerated)	7-80	13-58
Zinc		
Activated carbon adsorption		
granular	5-99	1-6,000
powdered	26-98	45-140
Chemical oxidation (ozone)	96	90-46
Chemical precipitation with sedimentation		
lime	25-99	2-26,000
alum	11-88	110-350,000
barium chloride	50	3
polymer/unspecified	10-99	ND-1,800,000
sodium carbonate	84-99	330-11,000
sodium hydroxide	80-99	44-560
combined precipitants	14-99	2-17,000
Chemical precipitation with filtration	82-99	10-60
Chemical reduction	87	21-1,500
Coagulation and flocculation	11-98	BDL-5,700
Filtration	0-99	16-18,000
Flotation	12-99	ND-53,000
Neutralization	99	30
Oil separation	88-97	BDL-680
Reverse osmosis	31-99	2-8,600
Sedimentation	0-99	BDL-100,000
Ultrafiltration	75-98	BDL-420
Activated sludge	0-92	BDL-38,000
Lagoons		
aerated	34-99	49-510
non-aerated	86	100-120
Bis(chloromethyl)ether		
Activated sludge	99	ND
Dimethyl phthalate		
Filtration	99-99	ND-BDL
Reverse osmosis	18-84	1-170
Sedimentation	98-99	ND-93
Activated sludge	99-99	ND-200
Diethyl phthalate		
Chemical precipitation with sedimentation		
lime	36	BDL-73
sodium hydroxide	63-95	ND-92
combined precipitants	99	ND-3.0
Chemical precipitation with filtration	25-99	ND-75
Filtration	50-99	ND-11,000
Flotation	99	ND
Oil separation	92	65
Reverse osmosis	63-99[b]	BDL-1
Sedimentation	99-99	ND-44
Ultrafiltration	95[b]	BDL
Activated sludge	20-99	ND-69
Di-n-butyl phthalate		
Activated carbon adsorption (granular)	0-99	BDL-11
Chemical oxidation (ozone)	78	2.7
Chemical precipitation with sedimentation		
lime	93[b]	BDL-BDL
alum	93-99	ND-550
FeCl(3)	5	5.4
combined precipitants	97-99	ND-ND
Coagulation and flocculation	0	BDL-0.6
Filtration	0-96	ND-1,300
Flotation	0-99	ND-300
Oil separation	94	49

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
Reverse osmosis	38-99[b]	BDL-11
Sedimentation	83	BDL-36
Ultrafiltration	86	13
Activated sludge	84-99	ND-7
Lagoons (aerated)	99	ND
Trickling filters	25	6
Di-n-octyl phthalate		
Activated carbon adsorption (granular)	20	4
Coagulation and flocculation	90	ND
Filtration	50-99	ND-4
Flotation	61-99	ND-33
Activated sludge		5,000
Bis(2-ethylhexyl)phthalate		
Activated carbon adsorption		
granular	26-66	4.7-410
powdered	97	10
Chemical precipitation with sedimentation		
lime	41-99	ND-40
alum	0-99	ND-67
barium chloride	95	2.4
polymer/unspecified	50	BDL
sodium hydroxide	73-92	BDL-52
combined precipitants	96	BDL-10
Chemical precipitation with filtration	95	BDL-84
Coagulation and flocculation	16-91	BDL-44
Filtration	21-98	BDL-16,000
Flotation	10-98	30-1,100
Oil separation	91-94	44-130
Reverse osmosis	25-99[b]	BDL-31
Sedimentation	0-80	BDL-170
Ultrafiltration	99[b]	BDL
Activated sludge	15-99	ND-220
Lagoons		
aerated	26-99	ND-28
non-aerated	72-99	ND-11
Trickling filters	83	6
Butyl benzyl phthalate		
Activated carbon adsorption (granular)	53-99	BDL-17
Chemical oxidation (ozone)	98[b]-98[b]	*BDL*-BDL
Chemical precipitation with sedimentation (lime)	99[b]	BDL-BDL
Coagulation and flocculation	94	BDL
Filtration	52-99	ND-10
Flotation	97-99	ND-42
Reverse osmosis	20-98	BDL-0.8
Sedimentation	95	ND-BDL
N-nitrosodiphenylamine		
Chemical precipitation with sedimentation (polymer/unspecified)	99	ND
Filtration	99	ND-0.4
Flotation	66	620
Sedimentation	99	ND
Activated sludge	69-99	ND-1.6
N-nitrosodi-n-propylamine		
Filtration	99	ND-BDL
Benzidine		
Activated sludge	0	4
Phenol		
Activated carbon adsorption		
granular	0-98	BDL-49
powdered	85	10
Chemical precipitation with sedimentation		
lime	69[b]	BDL
alum	0-99	ND-140
combined precipitants	33-96	10-47
Coagulation and flocculation	75-91	BDL-3
Filtration	22-99	ND-34,000
Flotation	0-80	9-2,400
Oil separation	99	ND-820
Reverse osmosis	80	0.2-0.7
Sedimentation	33-99	BDL-670
Solvent extraction	3-96	2,220-4,600,000
Activated sludge	8-99	ND-1,400
Lagoons (aerated)	ND-24	25-99
2-chlorophenol		
Filtration	0	2-17
Oil separation	99	ND
Sedimentation	99	BDL
Activated sludge	92-99	ND-100

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
2,4-dichlorophenol		
Chemical precipitation with sedimentation (sodium carbonate)	99	ND
Filtration	63-99	ND-2
Sedimentation	98	10-48
2,4,6-trichlorophenol		
Filtration	80	69
Oil separation	99	ND
Ultrafiltration	99	ND
Activated sludge	37-99	ND-4,300
Lagoons (aerated)	99	ND
Pentachlorophenol		
Activated carbon adsorption (granular)	59-99	BDL-49
Chemical precipitation with sedimentation (alum)	99	100
Filtration	99	ND-12
Flotation	19	5-30
Sedimentation	55	12-24
Activated sludge	67-99	ND-3,100
Lagoons (aerated)	99	ND-ND
2-nitrophenol		
Sedimentation	99	ND
Activated sludge	99-99	ND-BDL
4-nitrophenol		
Activated sludge	99	ND
Lagoons (aerated)	23	10
2,4-dinitrophenol		
Chemical precipitation with sedimentation (polymer/unspecified)	99	ND
Activated sludge	99	ND
2,4-dimethylphenol		
Chemical precipitation with sedimentation (lime)	48-88[b]	BDL-11
Flotation	99	ND-28
Sedimentation	99	ND
Activated sludge	99	ND-8
Total phenols		
Activated carbon adsorption		
granular	38-97	5-4,300
powdered	99-99	10-60
Chemical oxidation (ozone)	50-90	10-130
Chemical precipitation with sedimentation		
lime	0-99	60-1,600
alum	8-56	28-220,000
FeCl(3)	33	20
sodium hydroxide	90	60-70
combined precipitants	48-99	ND-1,300
Chemical precipitation with filtration	99	ND
Coagulation and flocculation	0-26	20-340
Filtration	0-60	10-64,000
Flotation	3-94	10-23,000
Oil separation	0-43	20-1,600
Reverse osmosis	5-81	12-20
Sedimentation	0-96	5-84
Ultrafiltration	27	16
Activated sludge	11-99	7-18
Lagoons		
aerated	33-99	3-20
non-aerated	40	30-50
Trickling filters	97	1,000
p-Chloro-m-cresol		
Activated carbon adsorption (granular)	17	BDL-BDL
Chemical precipitation with lime	44	62
Activated sludge	94-99	ND-4
Cresol		
Solvent extraction	74-98	800-330,000
Benzene		
Activated carbon adsorption (granular)	64-90	BDL-210
Chemical oxidation (ozone)	80[b]	BDL
Chemical precipitation with sedimentation		
lime	99	ND-1.0
alum	99	ND-310
polymer/unspecified	35	720
sodium hydroxide	99	2.0
combined precipitants	50-90	46-3,800

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
Reverse osmosis	30-80	0.4-1.4
Sedimentation	64-99	ND-2,400
Solvent extraction	75-97	7,000-35,000
Ultrafiltration	99[b]	ND
Activated sludge	75-99	ND-64
Lagoons (aerated)	74-95	5-10
Chlorobenzene		
Activated carbon adsorption (granular)	98	BDL
Activated sludge	38-99	ND-100
1,2-dichlorobenzene		
Activated carbon adsorption (granular)	99	BDL-5.4
Chemical precipitation with sedimentation (alum)	99	ND-0.05
Coagulation and flocculation	99	BDL-13
Flotation	76	18-260
Oil separation	99	ND
Activated sludge	69-99	ND-69
Lagoons (aerated)	99	ND
1,3-dichlorobenzene		
Oil separation	99	ND
Activated sludge	99	ND
1,4-dichlorobenzene		
Activated sludge	79-99	ND-21
Lagoons (aerated)	99	ND
1,2,4-trichlorobenzene		
Activated carbon adsorption (granular)	99	ND-94
Chemical precipitation with sedimentation (alum)	91	150-150
Coagulation and flocculation	91	150
Activated sludge	49-99	ND-920
Hexachlorobenzene		
Activated sludge	97-99	ND-0.8
Ethylbenzene		
Activated carbon adsorption (granular)	50	BDL-1.3
Chemical precipitation with sedimentation		
alum	70-99	ND-38,000
Oil separation	18	330-630
Reverse osmosis	0-64	4-6
Sedimentation	17-99	BDL-1,100
Stripping (steam)	54-87	130,000
Activated sludge	69-99	0.9-250
Lagoons (aerated)	91-97	5-1,000
Chloroform		
Activated carbon adsorption (granular)	64-99	ND-18
Chemical precipitation with sedimentation		
lime	99	ND-BDL
alum	40-99	ND-550
sodium carbonate	33	2.0
sodium hydroxide	91	5
combined precipitants	94	BDL-4,700
Filtration	50	BDL-500
Flotation	20-99	ND-24
Reverse osmosis	0-93[b]	BDL-31
Sedimentation	0-74	2-230
Stripping (steam)	49-99	ND-65,000
Activated sludge	9-99	ND-58
Lagoons (aerated)	99	ND-1,000
Carbon tetrachloride		
Chemical precipitation with sedimentation		
alum	94	65-180
polymer/unspecified	99	ND
combined precipitants	99	ND
Coagulation and flocculation		
Filtration	89-99	ND-55
Flotation	75	BDL-210
Sedimentation	99	ND
Activated sludge	98	BDL-0.1
Chloroethane		
Activated carbon adsorption (granular)	0-99	ND-240,000
1,1-dichloroethane		
Activated carbon adsorption (granular)	42-99	ND-45,000
Filtration	0-99	ND-180
Sedimentation	0	2
Activated sludge	99-99	ND-290

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
polymer/unspecified	81	130
combined precipitants	98-99	ND-22
Coagulation and flocculation	98	BDL-1.3
Flotation	3-99	ND-970
Oil separation	83	ND-BDL
Reverse osmosis	0-33	1-1
Sedimentation	64-99	ND-2,400
Solvent extraction	97	4,000
Activated sludge	77-99	ND-3,000
Lagoons (aerated)	99	ND
Nitrobenzene		
Chemical precipitation with sedimentation		
alum	68-99	ND-35
combined precipitants	99	5
Ultrafiltration	71[b]	BDL
Toluene		
Activated carbon adsorption (granular)	23-99	BDL-630
Chemical oxidation (ozone)	31	0.9-1.2
Chemical precipitation with sedimentation		
lime	0-99	ND-5.0
alum	0-73	3-3,600
polymer/unspecified	39	1,900
FeCl(3)	0	1.1
combined precipitants	84-96	73-4,200
Coagulation and flocculation	74	BDL-14
Flotation	10-99	ND-2,100
Oil separation	83	ND-BDL
Reverse osmosis	12-15	0.7-29
Sedimentation	17-83	BDL-1,100
Solvent extraction	94-96	1,600-2,300
Activated sludge	17-99	ND-1,400
Lagoons (aerated)	95-99	ND-BDL
2,6-dinitrotoluene		
Activated sludge	99	ND-200
Styrene		
Solvent extraction	93	1,000
Xylenes		
Filtration	75	12,000
Flotation	95-99	ND-1,000
Oil separation	58	10
Solvent extraction	97-98	1,000-1,000
2-chloronaphthalene		
Flotation	0	17
Reverse osmosis		1.4
Benzo(a)anthracene		
Chemical precipitation with sedimentation (sodium hydroxide)	64	BDL
Oil separation	9	10
Benzo(b)fluoranthene		
Chemical oxidation (ozone)	90[b]	BDL
Oil separation	9	10
Reverse osmosis		2.1-12
Sedimentation	86-99	ND-BDL
Benzo(k)fluoranthene		
Activated carbon adsorption (granular)	90	BDL
Sedimentation	99	ND
Benzo(a)pyrene		
Activated carbon adsorption (granular)	95	BDL-0.8
Chemical oxidation (ozone)	95[b]	BDL
Chemical precipitation with sedimentation (lime)	91[b]	ND-BDL
Oil separation	23	10
Sedimentation	83-99	ND-10
Ideno(1,2,3-c,d)pyrene		
Activated sludge	99	ND
Benzo(ghi)perylene		
Sedimentation	99	ND
Acenaphthene		
Chemical precipitation with sedimentation (lime)	75[b]	BDL
Filtration	73-99	ND-10
Oil separation	99	6
Reverse osmosis	9-99[b]	BDL
Sedimentation	99	ND-53
Activated sludge	0-99	ND-2.0

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
Acenaphthylene		
Reverse osmosis		1-1.6
Sedimentation	99	ND-19
Anthracene		
Activated carbon adsorption (granular)	50-97	BDL-0.4
Chemical oxidation (ozone)	98	BDL-0.4
Chemical precipitation with sedimentation		
lime	99	ND-BDL
polymer/unspecified		BDL
FeCl(3)	50	0.1
Filtration	0-99	ND-32,000
Flotation	45-98	0.2-600
Oil separation	99	ND
Reverse osmosis	77-99	BDL-1
Sedimentation	0-92	BDL-51
Activated sludge	52-99	ND-500
Chrysene		
Chemical precipitation with sedimentation		
lime	99	ND-10
polymer/unspecified	99	ND
sodium hydroxide	64	BDL
Oil separation	9	10
Sedimentation	0	10-19
Fluoranthene		
Activated carbon adsorption (granular)	88-95	BDL-BDL
Chemical precipitation with sedimentation		
lime	98[b]	ND-BDL
polymer/unspecified	99	ND
Filtration	20-50	0.05-93
Reverse osmosis	63-98	BDL-7.4
Sedimentation	64-99	ND-33
Activated sludge	0	2
Fluorene		
Chemical oxidation (ozone)	50	0.1
Chemical precipitation with sedimentation		
lime	99[b]	ND-BDL
sodium hydroxide	88	BDL
Oil separation	99	ND
Sedimentation	40-99	ND-23
Activated sludge	99-99	ND-ND
Naphthalene		
Activated carbon adsorption		
granular	51	78
powdered	96	10
Chemical precipitation with sedimentation		
lime	97[b]	ND-BDL
sodium hydroxide	77	1.0
combined precipitants	33-70	BDL-10
Filtration	86	BDL-160
Flotation	33-99	ND-840
Reverse osmosis	99[b]	BDL
Sedimentation	41-99	ND-23
Activated sludge	0-99	ND-260
Lagoons		
aerated	99	ND
non-aerated	99	ND
Phenanthrene		
Activated carbon adsorption (granular)	97-99	BDL-BDL
Chemical precipitation with sedimentation (lime)	92-99	ND-BDL
Coagulation and flocculation		
Filtration	67	ND-32,000
Flotation	45-98	0.2-600
Oil separation	99	ND
Reverse osmosis	99[b]	BDL
Sedimentation	0	BDL-40
Activated sludge	52-99	ND-500
Pyrene		
Activated carbon adsorption (granular)	95-98	BDL-BDL
Chemical oxidation (ozone)	67	0.1
Chemical precipitation with sedimentation (polymer/unspecified)	99	ND
Filtration	0-10	0.09-3,200
Flotation	0	0.3-18
Oil separation	99	ND

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
Reverse osmosis	19-99[b]	BDL-3.9
Sedimentation	19-99	ND-21
Activated sludge	78	0.1-9
Aroclor 1016		
Filtration	16	480
Oil separation	98	BDL-8
Aroclor 1221		
Filtration	20	650
Oil separation	97	BDL-6
Aroclor 1232		
Filtration	16	480
Oil separation	98	BDL-8
Aroclor 1242		
Filtration	20	650
Oil separation	97	BDL-6
Aroclor 1248		
Filtration	16	480
Oil separation	98	BDL-8
Aroclor 1254		
Filtration	20	650
Oil separation	97	BDL-6
Aroclor 1260		
Filtration	16	480
Oil separation	BDL-8	98
Methyl chloride		
Sedimentation	84	BDL-39
Methylene chloride		
Activated carbon adsorption (granular)	0-99	1.8-940
Chemical precipitation with sedimentation		
lime	33	BDL-39
alum	94	ND-1,300
polymer/unspecified	93-93	BDL-130
FeCl(3)	92	14
sodium hydroxide	90	1-90
combined precipitants	13	900-9,800
Coagulation and flocculation	56	70-100
Filtration	5-99	ND-31,000
Flotation	0-84	2-6,000

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
1,2-dichloroethane		
Activated carbon adsorption (granular)	21-99	ND-760,000
Chemical precipitation with sedimentation (alum)	99	ND-90
Stripping (steam)	70-99	5.9-440,000
Solvent extraction	99	20,000
1,1,1-trichloroethane		
Activated carbon adsorption (granular)	99-99	ND-1.9
Chemical oxidation		
Chemical precipitation with sedimentation		
alum	55	10-170
sodium hydroxide	0-99	ND-1
Chemical precipitation with filtration	75	0.3-1.0
Filtration	86-99	ND-4,400
Flotation	22-99	ND-860
Sedimentation	19-96	2-2,500
Stripping (steam)	9	42,000
Activated sludge	99-99	ND-3.3
Lagoons (aerated)	96	22
1,1,2-trichloroethane		
Activated carbon adsorption (granular)	99-99	ND-ND
Chemical precipitation with sedimentation		
sodium hydroxide	50	1.0
combined precipitants	99	ND-ND
Stripping (steam)	98-99	ND-200
Solvent extraction	90	16,420
1,1,2,2-tetrachloroethane		
Stripping (steam)	99-99	100-78,000
Solvent extraction	92	4,200
Activated sludge	99	ND-BDL
Vinyl chloride		
Activated carbon adsorption (granular)	52	1,100-9,600
1,2-dichloropropene		
Activated carbon adsorption (granular)	65-99	ND-BDL

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
Chemical precipitation with sedimentation (combined precipitants)		
Activated sludge	99-99	ND-ND
1,3-dichloropropane		
activated sludge	99	ND-0.89
Dichlorobromomethane		
Coagulation and flocculation	75	BDL
Flotation	99	ND
Activated sludge	99	ND-1.5
Chlorodibromomethane		
Chemical precipitation with sedimentation		
lime	99	ND
combined precipitants	99	ND-ND
Sedimentation	99	ND-1
Trichlorofluoromethane		
Flotation	99	ND
Stripping (steam)	24	34,000
Activated sludge	96	1.7-89
Trichloroethylene		
Activated carbon adsorption (granular)	58-99	BDL-5
Chemical precipitation with sedimentation		
lime		
alum	10-99	17
combined precipitants	99	ND-300
Filtration	0-99	ND-2,000
Flotation	86	130
Sedimentation	21-93	33-3,000
Stripping (steam)	99-99	ND-ND
Activated sludge	56-99	ND-84
1,1-dichloroethylene		
Activated carbon adsorption (granular)	99	ND-1.4
Chemical precipitation with sedimentation (alum)	99	ND-22
Filtration	52-57	ND-130
Sedimentation	87	40-70
1,2-trans-Dichloroethylene		
Activated carbon adsorption (granular)	96-98	1.1-140
Chemical precipitation with sedimentation (alum)	27	5-190
Sedimentation	38-44	5-19
Stripping (steam)	9-99	15,000-1,300,000
Tetrachloroethylene		
Activated carbon adsorption (granular)	68	BDL-32
Chemical oxidation (ozone)	99	ND
Chemical precipitation with sedimentation		
alum	99	ND-700
sodium hydroxide	99	ND
combined precipitants	95-99	ND-7
Filtration	0-0	ND-210
Flotation	0-99	ND-1,000
Oil separation	13-99	ND-71
Sedimentation	21-99	ND-3,000
Stripping (steam)	37-99	ND-6,800
Ultrafiltration	93	200
Activated sludge	55-99	ND-40
Lagoons (aerated)	99	ND
Alpha-endosulfan		
Oil separation	99	ND
Alpha-BHC		
Coagulation and flocculation	91	BDL
Filtration	77	1.9-6
Oil separation	86	ND-BDL
Ultrafiltration	79[b]	BDL
Beta-BHC		
Filtration	21	55
Ultrafiltration	50[b]	BDL
Activated sludge	99	ND
Gamma-BHC		
Filtration	64	BDL
4,4'-DDE		
Ultrafiltration	64[b]	BDL
4,4'-DDT		
Chemical precipitation with sedimentation (alum)	52	1
Coagulation and flocculation	76	BDL

Treatment Process	Range of Removal (%)	Range of Effluent Conc. (g/L)
Endrin aldehyde		
Oil separation	99	ND
Heptachlor		
Chemical precipitation with sedimentation (alum)	29	1.0
Coagulation and flocculation	64	BDL
Activated sludge	75	1.6
Chlordane		
Filtration	37	24
Acrolein		
Filtration	99	ND
Isophorone		
Chemical precipitation with sedimentation (lime)	6	560
Flotation	99	ND
Sedimentation	35–99	ND–110
Activated sludge		BDL–BDL

Notes: BLD = below detection limit; ND = not detected.
[a]Range of effluent conc. (fibers/L).
[b]Approximate value.